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THE QUALITY OF METAL PRODUCTS MADE ON CNC MACHINES

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ABSTRACT

Contemporary market must provide products that adapt to customer needs, which requires large investments and long-term employment. Producers have to take care of the buyers' different way of thinking. The quality of products and services is an important economic indicator. The paper presents studies and research in the field of bending of metal parts (thickness between 1 and 3 mm) on CNC machines. This paper tries to provide answers to the many problems arising in the companies due to the quality of the economic goods. In the technological flow of the achievement of a metal product, bending is very important, the quality and conformity of the product depending on this operation. The paper proposes laborious research and studies on determining the drawings of metal parts with the thickness between 1 and 3 mm, considering that other variables such: the temperature variation during the processes of punching and bending, tool usage, the tolerance between the surfaces of the bending tools, the vibrations of the machines, their usage and the roughness of the sheet metals may influence the quality and precision of the products. The calculation of the drawing (the geometry in plane of the piece) becomes important because it must include the deformation caused by the bending operation. Bending coefficients $K_î$ must compensate for deviations from the final dimensions of the metal parts, because of the many variables that can adversely affect their execution. The bending coefficient $K_î$ is determined by experimental tests and measurements.

KEYWORDS: bend metallic component; quality, conformity, other variables, CNC machines

1. Introduction

The research was made in multiple stages in two companies, on machines with different CNs. In the first stage were determined the bending coefficients K_i for metal marks with a thickness between 1 and 3 mm, on the following machines with CN:

- Stamping machine TC 200R;
- Bending Machine type SAFAN.

The bending coefficients resulted after the tests and measurements determined the extension of the research on other machines with CN. The second stage of the research introduced a variety of possibilities used to determine the drawings (flat patterns) of the components. The machines used to create the metal components were:

- Stamping machine TruPunch 3000R with CN;
- Bending Machine ERM 30135.

The drawings were calculated in four ways:

a) The drawing of the single part calculated using the bending coefficient K_{Ai} resulted in the first stage;

b) The drawing calculated mathematically on neutral fiber;

c) The drawing calculated on neutral fiber using the coefficients K_{Ei} obtained from the table;

d) The drawing calculated by the bending machine software.

The purpose of the research is to determine the optimal bending coefficient for the components to be obtained with the highest precision. The bending coefficients $K_î$ obtained after the experimental determinations were highlighted tabularly. They can be introduced in the computer aided design program (CAD - Computer Aided Design) for the metal components to be processed using CN machines (CAM - Computer aided - manufacturing). The input of the research for manufacturing components that follow the deviation of measures highlighted the importance of the quality of metallic marks.

2. Technical requirements

The global economic system allowed the debut of ISO 9000 standards and the instruction of real professionals, which had a powerful impact in the commercial trades between countries [1]. There was a significant leap in quantity and quality in commercial trades, determining a new international economic order [2]. The quality of products and benefits became a priority due to the degree of utility and the need of maximizing the consumer satisfaction. The study and research conducted and presented in this essay focuses on the manufacturing of metal marks made of OL37 with 2.5 mm thickness. The quality and precision of the samples obtained are affected by the presence of variables caused by the machines that perform various activities and also by the tools used and elements that create a system (machine / tool) for achieving the desired purpose [3]. These variables are not included in the software used for the computer aided design and manufacturing [3].

2.1. Semi-manufactured cutting

The calculation of the drawings is important because it contains also the deformations created during the bending process. The metal marks made of metal sheet with g = 2.5 mm were manufactured using the stamping machine TruPunch 3000R. Three types of samples with a gradual degree of complexity were manufactured. For each type of drawing, four types of calculations were used. For the component “L support” (Fig. 1), 4 types of samples were suggested, depending on the drawings (flat patterns) calculated. The bending coefficient ($K_î$) obtained has been included in the calculation of the drawings as seen in Fig. 2, Fig. 3, Fig. 4 and Fig. 5.

The drawing of sample no. 1 image 25-1-L was calculated using the bending coefficient resulted from the previous research $K_{Aî}$ = 0.52 mm / bending on a 90-degree angle.

$$\begin{aligned} L_1 &= \ell_1 - g + \ell_2 - g + K_{Ai} \\ L_1 &= 20 - 2.5 + 30 - 2.5 + 0.52 \\ L_1 &= 45 + 0.52 \\ L_1 &= 45.52mm \end{aligned} \tag{1}$$

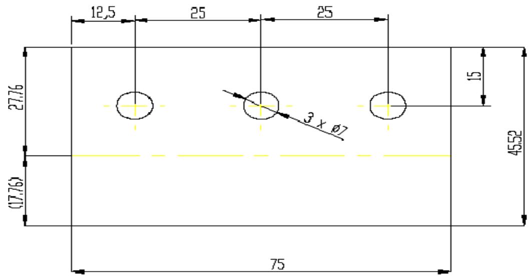

***Fig. 2.** The drawing of sample no. 1 (L Support)*

Sample no. 2 image 25-2-L has the drawing calculated from the neutral fiber [5].

$$\begin{aligned} L_2 &= \ell_1 + \ell_2 + \ell_\varphi \\ L_2 &= 20 - 2\times g + 30 - 2\times g + \frac{\pi\times 90^0}{180^0}(r + 0.45\times g) \\ L_2 &= 20 - 2\times 2.5 + 30 - 2\times 2.5 + 1.57(2.5 + 0.45\times 25) \\ L_2 &= 40 + 1.57\times 3.625 \\ L_2 &= 40 + 5.69125 \\ L_2 &= 45.69125mm \end{aligned} \tag{2}$$

For the drawing of sample no. 2, the following information was used: φ= 90º; r = 2.5 mm; x = 0.45 [8]; g = 2.5 mm.

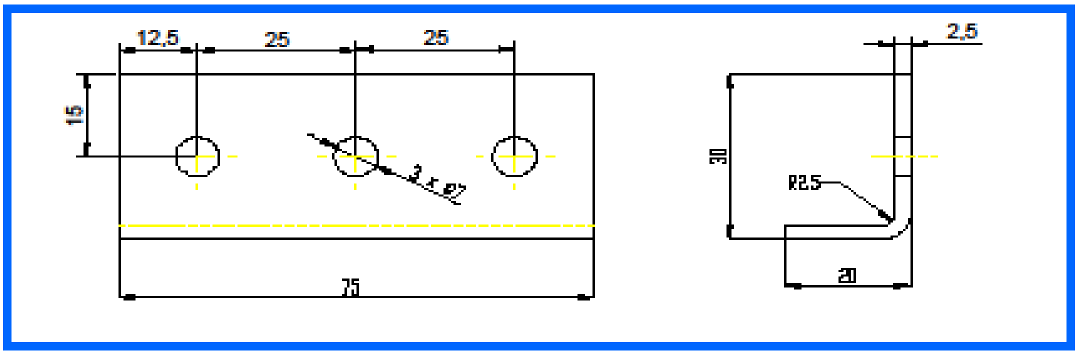

***Fig. 1.** L Support (Sample: no. 1, no. 2, no. 3, no. 4)*

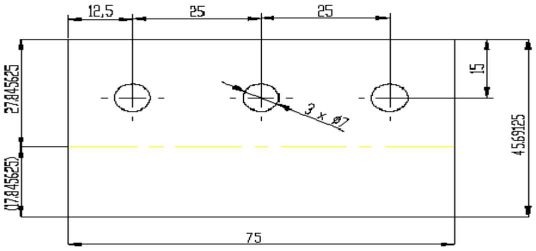

***Fig. 3.** The drawing of sample no. 2 (L Support)*

For the drawing of sample no. 3 image 25-3-L, the drawing of the neutral fiber was calculated using the bending coefficient K_{E3} = - 4.4 mm / bending at a 90-degree angle, depending on the thickness of the material g = 2.5 mm and the radius of the bending punch R = 2mm.

$$
\begin{aligned}
L_3 &= \ell_1 + \ell_2 + K_{E3} \\
L_3 &= 20 + 30 - 4.4 \\
L_3 &= 50 - 4.4 \\
L_3 &= 45.6mm
\end{aligned}
\tag{3}
$$

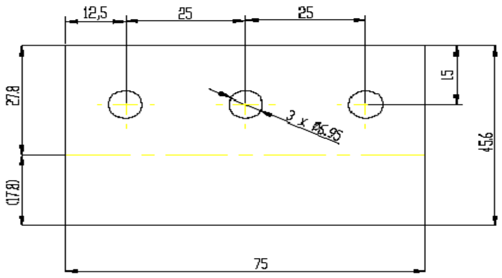

***Fig. 4.** The drawing of sample no. 3 (L Support)*

The drawing of sample no. 4 image 25-4-L was calculated by the software of the bending machine with CN (Numerical Command) [4].

$$
\begin{aligned}
L_4 &= \ell_1 - g + \ell_2 - g + K_{soft} \\
L_4 &= 20 - 2.5 + 30 - 2.5 + 0.52 \\
L_4 &= 45.52mm
\end{aligned}
\tag{4}
$$

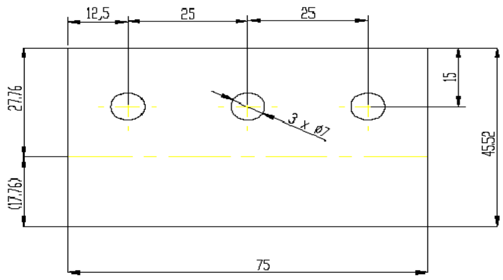

***Fig. 5.** The drawing of sample no. 4 (L Support)*

The profile of the component “U Support” is presented in Fig. 6. The 4 types of samples depending on the drawing calculated are described in Fig. 7, Fig. 8, Fig. 9 and Fig. 10.

The drawing of sample no. 5 image 25-1-U (Fig. 7) was calculated using the bending coefficient K_{Ai} resulted in the first stage of the research $K_{A\hat{i}}$ = 0.52 mm / bending at a 90-degree angle.

$$
\begin{aligned}
L_5 &= \ell_1 - g + \ell_2 - 2 \times g + \ell_3 - g + 2 \times K_{Ai} \\
L_5 &= 20 - 2.5 + 40 - 2 \times 2.5 + 20 - 2.5 + 2 \times 0.52 \\
L_5 &= 35 + 35 + 1.04 \\
L_5 &= 71.04mm
\end{aligned}
\tag{5}
$$

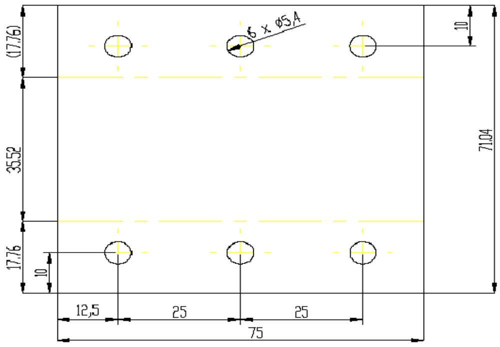

***Fig. 7.** The drawing of sample no. 5 (U Support)*

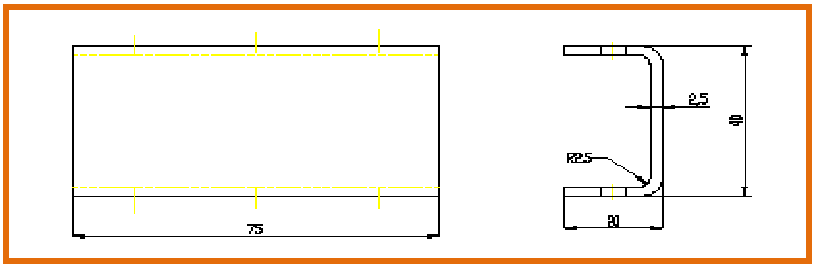

***Fig. 6.** U Support (Sample: no. 5, no. 6, no. 7 and no. 8)*

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For sample no. 6 image 25-2-U (Fig. 8) the drawing was calculated on neutral fiber [5].

$$
\begin{aligned}
L_6 &= \ell_1 + \ell_2 + \ell_3 + 2\times \ell_\varphi \\
&= 20 - 2\times g + 40 - 4\times g + 20 - 2\times g + 2\times \frac{\pi \times 90^0}{180^0}(r + 0.45\times g) \\
&= (20-5)\times 2 + 40 - 4\times 2.5 + 3.14\times(2.5 + 0.45\times 2.5) \\
&= 30 + 30 + 3.14\times(2.5 + 1.125) \\
&= 60 + 3.14x3.625 \\
&= 60 + 11.3825 \\
&= 71.3825.mm
\end{aligned} \tag{6}
$$

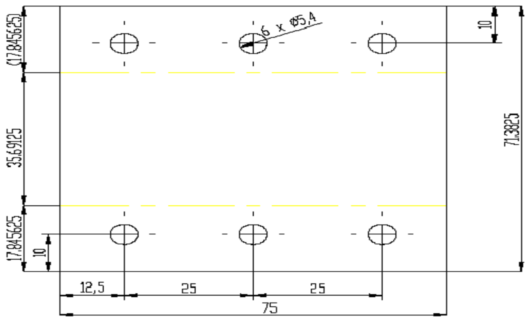

Fig. 8. *The drawing of sample no. 6 (U Support)*

The drawing of sample no. 7 image 25-3-U was calculated according to the coefficient de K_{E3} = -4.4 mm / bending at a 90-degree angle (Fig. 9).

$$
\begin{aligned}
L_7 &= \ell_1 + \ell_2 + \ell_3 + 2\times k_{E3} \\
L_7 &= 20 + 40 + 20 - 2\times 4.4 \\
L_7 &= 80 - 8.8 \\
L_7 &= 71.2mm
\end{aligned} \tag{7}
$$

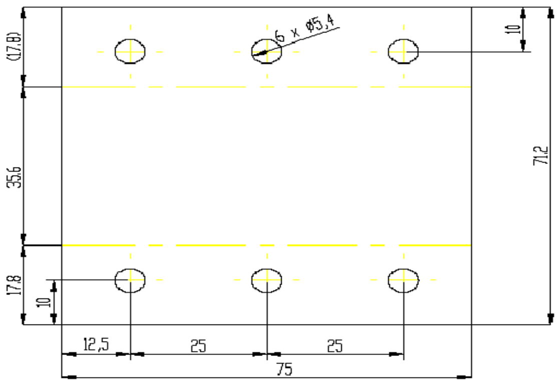

Fig. 9. *The drawing of the sample no. 7 (U Support)*

The drawing of the sample no. 8 image 25-4-U was calculated by the software of the bending machine with C.N (Fig. 10).

$$
\begin{aligned}
L_8 &= \ell_1 - g + \ell_2 - 2\times g + \ell_3 - g + 2\times k_{soft} \\
L_8 &= 20 - 2.5 + 40 - 2\times 2.5 + 20 - 2.5 + 2\times 0.52 \\
L_8 &= 35 + 35 + 1.04 = 71.04mm
\end{aligned} \tag{8}
$$

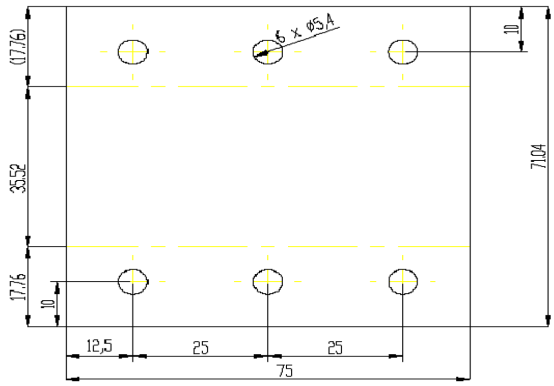

Fig. 10. *The drawing of the sample no. 8 (U Support)*

The profile of the “Ω Support” component is described in Fig. 11 and the drawings were calculated in four ways (Fig. 12, Fig. 13, Fig. 14, Fig. 15).

The drawing of the sample no. 9 image 25-1-Ω (Fig. 12) was calculated using the bending coefficient $K_{A\hat{i}}$ = 0.52mm/ bending at a 90-degree angle [5].

$$
\begin{aligned}
L_9 &= \ell_1 - g + \ell_2 - 2\times g + \ell_3 - 2\times g + \ell_4 - 2\times g + \ell_5 - g + 4\times K_{A\hat{i}} \\
L_9 &= 25 - 2.5 + 25 - 2\times 2.5 + 25 - 2\times 2.5 + 25 - 2\times 2.5 + 25 - 2.5 + 4\times 0.52 \\
L_9 &= 45 + 60 + 2.08 \\
L_9 &= 107.08mm
\end{aligned} \tag{9}
$$

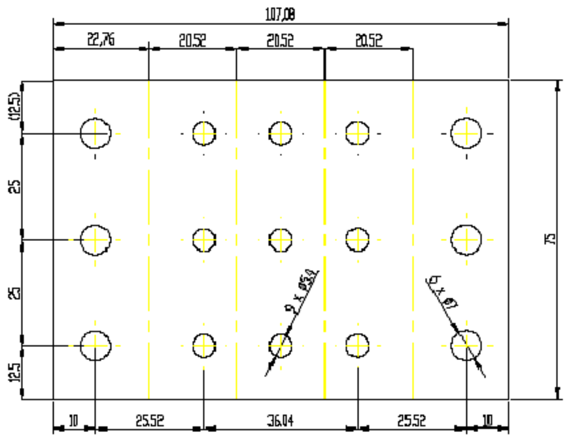

Fig. 12. *The drawing of sample no. 9 (Ω Support)*

The drawing of sample no. 10 image 25-2-Ω (Fig. 13) was calculated mathematically on neutral fiber according to the thickness of the material and the radius of the bending punch.

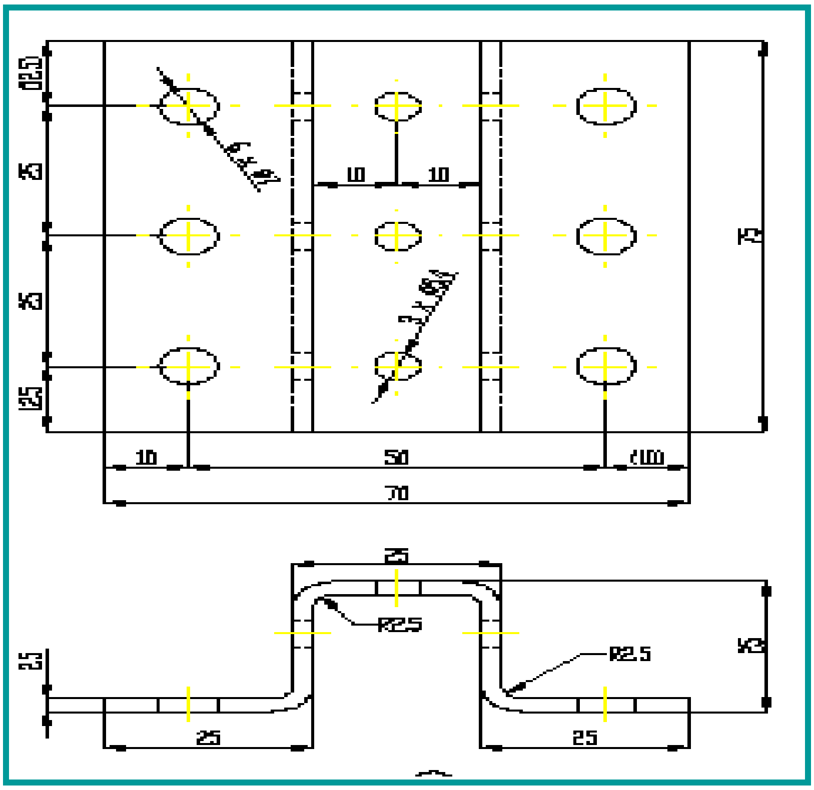

Fig. 11. Ω *Support (Sample: no. 9, no. 10, no. 11 and no. 12)*

$$
\begin{aligned}
L_{10} &= \ell_1 + \ell_2 + \ell_3 + \ell_4 + \ell_5 + 4\times \ell_\varphi \\
L_{10} &= 25-2\times g+25-4\times g+25-4\times g+25-4\times g+25-2\times g+4\times\frac{\pi\times 90^0}{180^0}(r+0.45\times g) \\
L_{10} &= (25-5)+(25-10)\times 3+25-5+3.14\times 2\times(2.5+0.45\times 2.5) \\
L_{10} &= 40+45+6.28\times 3.625 \\
L_{10} &= 85+22.765 \\
L_{10} &= 107.765.mm
\end{aligned}
\tag{10}
$$

$$
\begin{aligned}
L_{11} &= \ell_1 + \ell_2 + \ell_3 + \ell_4 + \ell_5 + 4\times k_{E3} \\
L_{11} &= 25+25+25+25+25-4x4.4 \\
L_{11} &= 125-17.6 \\
L_{11} &= 107.4mm
\end{aligned}
\tag{11}
$$

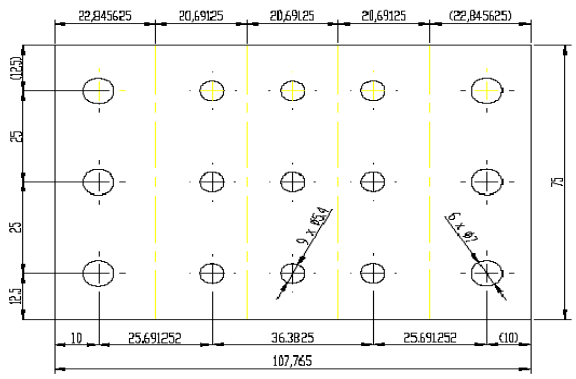

***Fig. 13.** The drawing of sample no. 10 (Ω Support)*

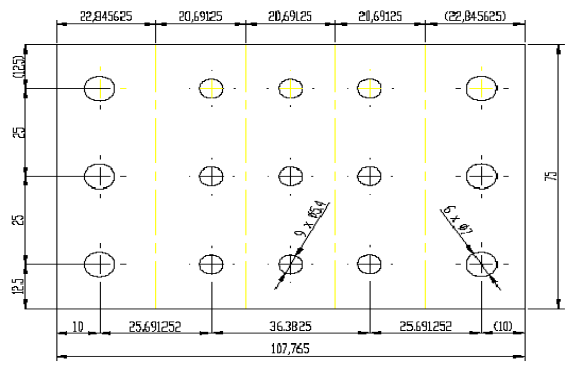

***Fig. 14.** The drawing of sample no. 11 (Ω Support)*

The drawing of sample no. 11 image 25-3-Ω (Fig. 14) was calculated on neutral fiber according to the bending coefficient K_{E3} = -4.4 mm / bending at a 90-degree angle.

The drawing of sample no. 12 image 25-4-Ω (Fig. 15) was calculated by the software of the bending machine with CN.

$$
\begin{aligned}
L_{12} &= \ell_1 - g + \ell_2 - 2\times g + \ell_3 - 2\times g + \ell_4 - 2\times g + \ell_5 - g + 4\times k_{soft} \\
L_{12} &= 25 - 2.5 + 25 - 2\times 2.5 + 25 - 2\times 2.5 + 25 - 2\times 2.5 + 25 - 2.5 + 4\times 0.5225 \\
L_{12} &= 45 + 60 + 2.09 \\
L_{12} &= 105 + 2.09 \\
L_{12} &= 107.09mm
\end{aligned} \quad (12)
$$

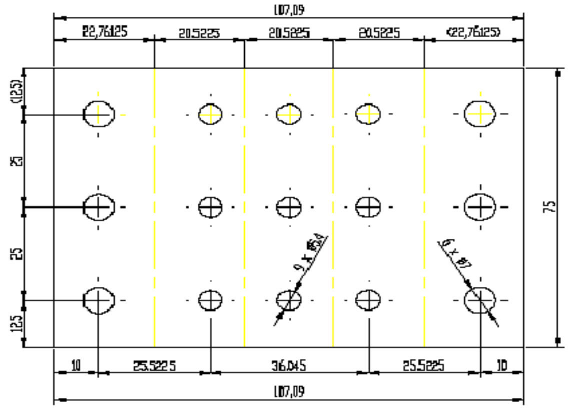

Fig. 15. *The drawing of sample no. 12 (Ω Support)*

The final data was centralized in Table 1. There are differences between the drawings and these differences increase gradually, depending on the complexity and the number of the bent component [6].

2.2. Measuring the benchmarks of the samples after stamping

The samples cut using the stamping machine TruPunch 3000R (table 2) were measured using the digital calipers Mitutoyo that has a precision of ± 0.01 mm. The stamping precision according to the specifications of the machine TruPunch 3000R is ± 0.1mm. From every type of sample five pieces were executed.

2.3. Bending semi-manufactured materials

The bends of the stamped samples were done through the bending process. The company where the research was made had an important processing center equipped with numerical controlled machines and the necessary tools and devices. The resulted benchmarks, consistent with the execution image, depend on the user's experience and professionalism.

Table 1. *The drawings calculated using the four methods*

Sample name (g = 2.5 mm)	The drawing determined by tests and measurements K_{Ai}	The drawing calculated on neutral fiber	The drawing calculated on neutral fiber with K_{E3} coefficient	The drawing calculated by the software of the bending machine
Sample no. 1÷4 - L support	45.52 mm	45.69125 mm	45.6 mm	45.52 mm
Sample no. 5÷8 - U support	71.04 mm	71.3825 mm	71.2 mm	71.04 mm
Sample no. 9÷12 - Ω support	107.08 mm	107.765 mm	107.4 mm	107.09 mm

Table 2. *The drawings calculated using the four methods*

Sample	Image	Nominal benchmark (mm)	Sample no. 1 (mm)	Sample no. 2 (mm)	Sample no. 3 (mm)	Sample no. 4 (mm)	Sample no. 5 (mm)
Sample no. 1	25-1-L	45.52	45.53	45.58	45.53	45.54	45.54
Sample no. 2	25-2-L	45.69125	45.71	45.7	45.71	45.71	45.7
Sample no. 3	25-3-L	45.6	45.61	45.62	45.63	45.61	45.63
Sample no. 4	25-4-L	45.52	45.52	45.57	45.57	45.56	45.53
Sample no. 5	25-1-U	71.04	71.05	71.03	71.09	71.01	71.05
Sample no. 6	25-2-U	71.3825	71.31	71.38	71.38	71.3	71.3
Sample no. 7	25-3-U	71.2	71.2	71.16	71.16	71.16	71.16
Sample no. 8	25-4-U	71.04	71.05	71.03	71.09	71.01	71.05
Sample no. 9	25-1-Ω	107.08	106.98	107.09	107.08	107.11	107.09
Sample no. 10	25-2-Ω	107.765	107.7	107.76	107.79	107.78	107.75
Sample no. 11	25-3-Ω	107.4	107.36	107.4	107.4	107.42	107.34
Sample no. 12	25-4-Ω	109.09	107.02	107.1	107.1	107.1	107.07

The fields of elastic and plastic deformation are a product of bending. The plastic and elastic deformation of the semi-manufactured material is produced only in the area near the bending line [7]. The tools used for the bending process were chosen according to the type of material, the thickness of the metal sheet and the configuration of the component, which positively influenced the quality and precision of the execution. For the calculation of the drawing was taken into consideration the type of punch and die used. A punch with R = 2 mm and a die with an opening V = 16 mm [9] were selected. The bending was done freely without calibration. The sequence of the bending operations used to create the benchmark "L Support" is described in Fig. 16.

The components created were measured and the data was centralized in Table 4. The deviations and the nominal benchmarks were also calculated in order to choose the most optimal option. The limits for the linear deviations are according to Table 3.

Fig. 16. *Bending samples no. 1, 2, 3, 4*

Table 3. *Maximum deviations to linear dimensions except for countersinks*

Execution	Benchmark 0.5 mm up to 3 mm	Benchmark 3mm up to 6 mm	Benchmark 6 mm up to 30 mm	Benchmark 30 mm up to 120 mm
Smooth	±0.05	±0.05	±0.1	±0.15
Medium	±0.1	±0.1	±0.2	±0.3
Rough	±0.2	±0.3	±0.5	±0.8
Coarse	-	±0.5	±1	±1.5

Table 4. *Deviations from the nominal benchmarks of sample 1, 2, 3, 4*

L Support	Component no.1 (mm)		Component no.2 (mm)		Component no.3 (mm)		Component no.4 (mm)		Component no.5 (mm)	
Nominal benchmark (mm)	20	30	20	30	20	30	20	30	20	30
Sample no. 1	19.86	30.19	20.04	30.07	19.86	30.5	19.98	30.10	19.79	30.2
Deviations from the nominal benchmarks (mm)										
	-0.14	+0.19	+0.04	+0.07	-0.14	+0.5	-0.02	+0.20	-0.21	+0.20
Sample no. 2	19.93	30.35	19.89	30.33	19.86	30.42	19.93	30.34	19.89	30.34
Deviations from the nominal benchmarks (mm)										
	-0.07	+0.35	-0.11	+0.33	-0.14	+0.42	-0.07	+0.34	-0.11	+0.34
Sample no. 3	19.92	30.27	19.86	30.31	19.80	30.42	19.88	30.30	19.93	30.30
Deviations from the nominal benchmarks (mm)										
	-0.08	+0.27	-0.14	+0.31	-0.20	+0.42	-0.12	+0.30	-0.07	+0.30
Sample no. 4	19.88	30.22	19.93	30.19	19.96	30.16	19.94	30.20	19.97	30.19
Deviations from the nominal benchmarks (mm)										
	-0.12	+0.22	-0.07	+0.19	-0.04	+0.16	-0.06	+0.20	-0.03	+0.19

For type "U Support" reference points, the benchmarks after the bending process and the deviations from the nominal benchmarks were centralized in Table 5. Fig. 17 describes the bending operations.

Table 5. *Deviations at nominal benchmarks for samples 5, 6, 7, 8*

U Support	Piece no. 1 (mm)			Piece no. 2 (mm)			Piece no. 3 (mm)			Piece no. 4 (mm)			Piece no. 5 (mm)		
Nominal benchmark (mm)	20	40	20	20	40	20	20	40	20	20	40	20	20	40	20
Sample no. 5	19.77	40.17	19.98	19.84	40.35	19.88	19.95	40.20	19.93	19.92	40.25	20.01	19.92	40.23	19.98
Deviations from the nominal benchmarks (mm)	-0.23	+0.17	-0.02	-0.16	+0.35	-0.12	-0.05	+0.20	-0.07	-0.08	+0.25	+0.01	-0.08	+0.23	-0.02
Sample no. 6	19.93	40.45	19.93	19.87	40.31	20.00	19.98	40.15	20.17	19.42	41.00	19.95	19.69	40.75	19.69
Deviations from the nominal benchmarks (mm)	-0.07	+0.45	-0.07	-0.13	+0.31	0	-0.02	+0.15	+0.17	-0.58	+1	-0.05	-0.31	+0.75	-0.31
Sample no. 7	19.99	40.33	19.99	19.95	40.29	20	19.98	40.36	20	19.98	40.36	19.92	19.95	40.25	20.02
Deviations from the nominal benchmarks (mm)	-0.07	+0.33	-0.01	-0.05	+0.299	0	-0.02	+0.36	0	-0.02	+0.36	-0.08	-0.05	+0.25	+0.02
Sample no. 8	19.89	40.53	19.87	19.98	40.56	19.95	20.01	40.51	19.93	19.99	40.56	19.98	20.04	40.54	19.97
Deviations from the nominal benchmarks (mm)	-0.07	+0.53	-0.13	-0.02	+0.56	-0.05	+0.01	+0.51	-0.07	-0.01	+0.56	-0.02	+0.04	+0.54	-0.03

Fig. 17. *Bending samples no. 5, 6, 7, 8*

The benchmarks obtained after bending the reference points type "Ω Support" were centralized in Table 6. The sequence of the bending operations is described in Fig. 18.

Table 6. *Deviations at nominal benchmarks for samples 9, 10, 11, 12*

Ω Support			Sample no. 9	Deviations from the nominal benchmarks (mm)	Sample no. 10	Deviations from the nominal benchmarks (mm)	Sample no. 11	Deviations from the nominal benchmarks (mm)	Sample no. 12	Deviations from the nominal benchmarks (mm)
Piece no.1	Nominal benchmark	25	24.80	-0.20	24.92	-0.08	24.82	-0.18	24.94	-0.06
		25	25.02	+0.02	24.97	-0.03	24.93	-0.07	25.14	+0.14
		25	24.96	-0.04	25.67	+0.67	25.56	+0.56	24.96	-0.04
		25	25.17	+0.17	25.08	+0.08	24.87	-0.13	25.00	0.00
		25	24.95	-0.05	24.92	-0.08	24.85	-0.15	24.95	-0.05
Piece no.2	Nominal benchmark	25	24.98	-0.02	24.94	-0.06	24.79	-0.21	24.86	-0.14
		25	25.11	+0.11	24.93	-0.07	25.05	+0.05	25.19	+0.19
		25	25.05	+0.05	25.86	+0.86	25.63	+0.63	25.28	+0.28
		25	25.11	+0.11	25.04	+0.04	24.92	-0.08	25.02	+0.02
		25	24.89	-0.11	24.98	-0.02	24.81	-0.19	24.90	-0.10
Piece no.3	Nominal benchmark	25	24.96	-0.04	24.95	-0.05	24.88	-0.12	24.88	-0.12
		25	25.04	+0.04	25.08	+0.08	24.98	-0.02	25.10	+0.10
		25	24.98	-0.02	25.90	+0.90	25.65	+0.65	25.12	+0.12
		25	24.98	-0.02	24.87	-0.13	24.88	-0.12	25.11	+0.11
		25	24.90	-0.10	24.93	-0.07	24.88	-0.12	24.90	-0.10
Piece no.4	Nominal benchmark	25	24.97	-0.03	24.91	-0.09	24.92	-0.08	24.91	-0.09
		25	25.13	+0.13	25.55	+0.55	24.89	-0.11	25.07	+0.07
		25	24.75	-0.25	25.96	-0.96	25.49	+0.49	25.17	+0.17
		25	25.11	+0.11	25.12	+0.12	25.09	+0.09	25.07	+0.07
		25	25.04	+0.04	24.91	-0.09	24.88	-0.12	24.89	-0.11
Piece no.5	Nominal benchmark	25	25.19	+0.19	24.92	-0.08	24.90	-0.10	24.89	-0.11
		25	25.34	+0.34	25.13	+0.13	25.10	+0.10	25.04	+0.04
		25	24.12	-0.88	25.18	+0.18	25.42	+0.42	25.33	+0.33
		25	25.3	+0.30	25.10	+0.10	25.10	+0.10	25.01	+0.01
		25	25.14	+0.14	25.06	+0.06	24.92	-0.08	24.81	-0.19

Fig. 18. *Bending samples no. 9, 10, 11, 12*

3. Conclusion

1. From the analysis and the comparison of the results obtained, it may be concluded that the dimensions of the stamped samples are between the accepted limits of the stamping machine tolerance TruPunch 3000.

2. The deviations from the nominal benchmarks are caused by the vibrations that occur during the stamping process, but also by the tools used during this process.

3. The stamping machine TruPunch 3000R is extremely capable and very productive, the transfer speed on axis Ox is 90 m/min and on axis Oy is 60 m/min [10]. The vibrations that occur during the stamping process are inevitable, but the usage of the tools also influences the quality in execution of the components.

4. The high speed in changing the tools, the movement route of the index on high routes, (the metal sheet has the surface of 1500 x 3000 mm^2) and the forces created during the stamping process that can reach up to 20 KN are factors that produce vibrations even if the machine is strongly constructed [10].

5. A negative influence in the execution of components using the stamping machine is the uneven appearance of the surfaces of the metal sheets due to lamination, as this has an uneven thickness.

6. After the samples were bent, the deviations from the nominal benchmarks were significant. We suggest determining the optimal bending coefficient by using an algorithm, which is the subject of another essay.

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