Analysis of Linear Dimension Accuracy of Sheet Metal Bending

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Abstract. Working on the design of the products obtained by the V-bending, the engineer uses the nominal thickness of the material. In this case, the problem is to evaluate the accuracy of the linear dimensions of the resulting products due to deviations in the thickness of the material and the manufacturing technology of the steel sheets. Article presents analysis of linear dimension accuracy for V-bending for the metal cold-rolled and hot-rolled sheets with thickness 1.0...8.0 mm and width from 1000...1500mm. Proposed method is based on the calculation of difference between nominal flat length and flat lengths corresponding maximum and minimum thickness of the metal sheet.

1 Introduction

V-bending of sheet metal is a widely used for metal forming in the manufacture of conveyors, elevators and other lifting and transport machines, because providing production time saving and minimizing the non-added-value activities [1, 2]. As known during the bending operation, the material outward of the neutral axis is strained while the inside material is compressed [3].

There are many works devoted to developing of the process design using finite element method (FEM) [4, 5], investigation of spring-back factor for different materials [6, 7], and accuracy of angular dimensions [8]. However, problem of linear dimension accuracy in V-bending process is not given much attention. The approximate values of the allowable deviations of the dimensions of the parts after bending are specified in [9], while for material thicknesses of 3.0...6.0 mm, the allowable errors are 1.5...3.0 mm. However, it is not clear how these values were obtained and what they take into account. The assigned deviations of the linear dimensions of the products in practice, as a rule, do not exceed 0.5...1.0 mm. Thus, insufficient coverage of the issue of determining the accuracy of linear dimensions, which is why it is impossible to determine the possibility of manufacturing it by V-bending by the assigned deviations in the dimensions of the product.

For example, when designing the detail of a pallet roller conveyor (Figure 1), the designer uses the nominal thickness s_n of the work piece, without taking into account the deviation of the material thickness specified in the standards [10, 11]. At the same time, the operator of the sheet bending press has uncertainty about entering data into the numerical software

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package: use the nominal thickness s_n of the material or the measured actual value of the thickness s_f of the work piece material during the bending process.

Fig. 1. Detail of pallet roller conveyor producing by V-bending

The article presents the results of research aimed at studying the problem of estimating the accuracy of linear dimensions for V-bending process.

2 Method for estimating the accuracy of linear dimensions

To develop a method for estimating the accuracy of linear dimensions in V-bending, it is necessary to take into account the product parameters, such as:

- technology for obtaining the material – cold-rolled or hot-rolled steel;
- sheet thickness;
- width and length of the sheet;
- precision manufacturing in thickness;
- maximum deviation in sheet thickness;
- bend angle.

Since the flat work piece is made according to the drawing using laser cutting on machines with a working table with dimensions of no more than 1500x3000 mm, we will assume that the width of the sheet lies in the range of more than 1000 to 1500 mm inclusive. The thickness accuracy of the sheet is normal (BT) for cold – rolled steel or normal (B) for hot-rolled steel. For products with a thickness of 1.0 to 5.0 mm, cold – rolled steel are used, and for products with a thickness of 3.5 to 8.0 mm, hot-rolled steel are used.

The thickness of the sheet due to its maximum deviation can vary significantly from s_{min} to s_{max} , and there is a bending accuracy equal to the difference between the nominal value of the flat length L_n and the lengths L_{min} and L_{max} corresponding to the thicknesses s_{min} and s_{max} .

In practice, for one detail are used one type of die and punch, then the flat length L of the work piece can be calculated as [12]:

$$L = (n - 1)v + \sum_{i=1}^n l_i, \quad (1)$$

where n – quantity of bends, v – compensation value of bend, i – number of bend, l_i – length of i -th bend.

Compensation value v depending from bend angle, bend radius and thickness of metal and can be calculated for common cases using [12]. In article we will consider details with 90° bend angle (Figure 2).

Fig. 2. Scheme for calculation of linear dimension accuracy.

Therefore, compensation value v :

$$v = \pi \left(\frac{180 - \beta}{180} \right) \left(r + \frac{s}{2} k \right) - 2(r + s), \quad (2)$$

where β – bend angle, r – bend radius, s – thickness, k – correction factor.

The correction factor k determines the position of the neutral axis in V-bending and can be calculated with empirical formula [12]:

$$k = 0,65 + 0,5 \log \frac{r}{s}. \quad (3)$$

When the metal thickness deviates from its nominal value, we get accuracy in the flat lengths Δ_{min} and Δ_{max} , corresponding to s_{min} and s_{max} :

$$\begin{cases} \Delta_{min} = L_{min} - L_n = nv_{min} + \sum_{i=1}^n l_i - nv_n - \sum_{i=1}^n l_i = n(v_{min} - v_n) \\ \Delta_{max} = L_{max} - L_n = nv_{max} + \sum_{i=1}^n l_i - nv_n - \sum_{i=1}^n l_i = n(v_{max} - v_n) \end{cases} \quad (4)$$

where v_{min} – compensation value of bend for s_{min} , v_{max} – compensation value of bend for s_{max} .

Taking into account equations (2) and (3):

$$\begin{cases} v_{min} = \frac{\pi}{2} \left(r + \frac{s_{min}}{2} k_{min} \right) - 2(r + s_{min}) \\ v_{max} = \frac{\pi}{2} \left(r + \frac{s_{max}}{2} k_{max} \right) - 2(r + s_{max}) \end{cases} \quad (5)$$

where k_{min} – correction factor for s_{min} , k_{max} – correction factor for s_{max} .

According to equations (4) and (5) and after transformations tolerance can be represented as:

$$\begin{cases} \Delta_{min} = n \left[\frac{\pi}{4} (s_{min} k_{min} - s_n k_n) - 2(s_{min} - s_n) \right] \\ \Delta_{max} = n \left[\frac{\pi}{4} (s_{max} k_{max} - s_n k_n) - 2(s_{max} - s_n) \right] \end{cases} \quad (6)$$

where k_{min} , k_{max} and k_n calculated with (3) for s_{min} , s_{max} and s_n respectively.

3 Results and discussion

The maximum thickness deviations for cold-rolled steel sheet with a width of 1000 ... 1500 mm of normal accuracy and hot-rolled steel sheet with a width of 1000...1500 mm of normal accuracy are given in Table 1 [10, 11].

Table 1. The maximum thickness deviations for cold-rolled and hot-rolled steel sheets with a width of 1000...1500mm of normal accuracy.

Nominal thickness s_n in mm	Cold-rolled steel sheet	Hot-rolled steel sheet
1.0	± 0.11	
1.5	± 0.13	
2.0	± 0.16	
2.5	± 0.18	
3.0	± 0.19	
3.5	± 0.22	± 0.21
4.0	± 0.22	+0.3 -0.5
4.5	± 0.23	
5.0	± 0.23	
5.5		
6.0		+0.25 -0.6
6.5		
7.0		
7.5		
8.0		+0.3 -0.8

Figures 3 and 4 presents the values of accuracy of linear dimensions Δ_{min} and Δ_{max} for cold-formed and hot-formed steel sheets according to the Table 1, equation 3-6 and taking the bend radius is equal to s_n .

Fig. 3. Accuracy of linear dimensions for V-bending of cold-formed steel sheets.

Fig. 4. Accuracy of linear dimensions for V-bending of hot-formed steel sheets.

The Figure 3 shows the accuracy of linear dimensions when using a cold-rolled steel sheets are symmetrical and do not exceed 0.38 mm. The accuracy of linear dimensions for hot-rolled steel sheets have a pronounced asymmetry, while the deviations in "+" are in the range of 0.35...1.32 mm, and in "-" - in the range of -0.35...-0.5 mm. The asymmetry of the accuracy is related to the asymmetry of the maximum deviations in the thickness of the hot-rolled sheet (see Table 1).

As can be seen from the results shown in Figure 4, the accuracy for sheet thicknesses of 4.0...5.5 mm and 6.0...7.5 mm are completely identical. This is due to the fact that the maximum deviations in the thickness of the hot-rolled sheet are given for a fairly wide range of thicknesses. Thus, the accuracy of linear dimensions is sufficient to calculate for one thickness from the range of sheet thicknesses.

To obtain a symmetrical accuracy, the engineer must focus on the development of products made of hot-rolled sheet not on its nominal thickness, but on the average thickness, taking into account the maximum deviations. For example, for a nominal sheet thickness of 4 mm, the engineer needs to use a sheet thickness of 3.9 mm. Then the accuracy of the linear dimensions will also correspond to the average value ± 0.66 mm.

4 Conclusion

The accuracy of the details using V-bending is affected by the technology of sheet manufacturing (cold-rolled or hot-rolled) due to the difference in the maximum deviations in the thickness of the sheet. If the thickness of the sheet deviates in a smaller direction from the nominal value, the tolerance is positive, in a larger direction-the tolerance is negative. At the same time, with a symmetrical deviation of the maximum thickness of the sheet, the accuracy are also symmetrical.

For products made of cold-rolled steel sheets with a thickness of 1.0 to 5.0 mm, the accuracy of linear dimensions are symmetrical in the range of $\pm 0.18... \pm 0.38$ mm. For products made of hot-rolled steel sheets with a thickness of 3.5 to 8.0 mm, the accuracy of linear dimensions in the vast majority of cases are asymmetric, while the deviations in "+" are in the range of 0.35...1.32 mm, the deviations in "-" are in the range of -0.35...-0.5 mm.

If it is necessary to obtain a symmetrical accuracy of linear dimensions, the engineer should not focus on the nominal thickness of the sheet when designing products, but on the average between the minimum and maximum thickness of the sheet.

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