

A variant of solving the optimization problem of finding the order of bending of sheet metal parts with parallel bends in time

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Abstract. The article proposes a solution to the optimization problem of finding the bending order with the smallest value of the objective function in time when bending complex profiles from a sheet metal with parallel bending lines (according to the OK12-93 classifier, subgroups 745410; 745420; 745430 and 745440). An algorithm is formulated for finding the most continuous bending order, formulas are derived that are necessary to calculate the sweep, technological dimensions for each transition and check the feasibility of subsequent bends, in the presence of perfect bends, a number of algorithms for compiling technological transitions to parts with 1, 2, 3 bends are also presented privately. The creation of this optimization algorithm made it possible to find options for bending orders that require the least time to manufacture a part and significantly reduced the time for technological calculations when drawing up a technological process.

Keywords: Bending, CNC, Sheet metal, Reducing bending time, Bending sequence.

1 Introduction

At the moment, at most enterprises, the calculation of unfolded sheet metal parts and the order of their bending is carried out manually by drawing each transition in CAD systems and checking the feasibility of subsequent transitions, if any. All attention is focused on obtaining a certain order of bending of the part, which provides a given bend profile, but is not optimal from the point of view of the minimum time spent on manufacturing the part. At the same time, each large foreign manufacturer of press brakes has its own expensive software, which is able to find the bending order of a

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part in automatic mode and visualize it, but it is not known whether it is the most optimal solution for a given part. In addition, this software has a number of disadvantages, among which the most significant are the price, the presence of functions that are not in great demand at most machine-building enterprises and the lack of domestic software. In this regard, it becomes necessary to create your own algorithm, and then software that can generate the correct bending orders in the shortest possible time and compare them in terms of execution time to find the least time-consuming bending order.

When developing a bending order, rules of thumb are used. They choose a bending order suitable for obtaining a given bending profile (that is, the feasibility of all transitions), the required tool for each transition, calculate the possibility of installing hardly several tools to reduce the total bending time - excluding the time for tool change. When developing a technological process, a process engineer has problems to optimize bending transitions. The functions of bending time T_{bend} (1) and bending cost F_{cost} (2) are considered as optimization in these problems:

$$t_{bend} = \sum_{i=1}^n T_i + \sum_{i=1}^n N_i + \sum_{i=1}^n M_i + \sum_{i=1}^n V_i \quad (1)$$

Where:

$i=1, 2, \dots, n$

n – the number of bends in the part;

T_i – time spent on placing the workpiece on the table (placing the workpiece on the table, bringing the workpiece to the stop);

N_i – time spent on changeover for bending to another size (changing the position of the back stops);

M_i – time spent on changing the tool (for example, to perform 2 or more bends at once);

V_i – time spent on the tool stroke (performing idle, working and reverse idling).

$$F_{cost} = \sum_{i=1}^n T_i F_b + \sum_{i=1}^n N_i F_s + \sum_{i=1}^n M_i F_{ch} + \sum_{i=1}^n V_i F_m \quad (2)$$

Where:

$i=1, 2, \dots, n$

n – the number of bends in the part;

F_b – cost of 1 unit of time for placing the workpiece;

F_s – cost of 1 unit of time for changeover;

F_{ch} – cost of 1 unit of time per tool change;

F_m – cost of 1 unit of time per tool stroke.

The components of the bending time T_{bend} and the cost of bending F_{cost} are related to each other by the coefficients (standard hours) laid down in each enterprise and consisting of fixed and variable costs, such as depreciation of equipment, cost of electricity, wages of a worker, etc. In this regard, this work will solve the problem of reducing the bending time T_{bend} of the part, and already on the basis of the gain obtained at each enterprise, it will be possible to estimate the gain in the cost of manu-

facturing each part, by multiplying the time obtained by certain coefficients (standard hours) and comparing the obtained cost with the cost previously pledged for this part.

To speed up the calculation of the order of bending, which ensures a given bend profile, it is necessary to empirically compose an algorithm for finding solutions to this problem. To find the least time-consuming variant of the bending order, it is necessary to derive from each transition the components of the total bending time given in formula (1), and calculate the time function T_{bend} and compare them. After comparing and searching for the smallest value of the bending time of a given profile, it will be possible to conclude that this order is the most advantageous in terms of time. Automation of this process will also give a significant benefit in the time of technological preparation for the production of a part and exclude cases of defects in manufacturing, due to the appearance of situations of impossibility of making subsequent bends in the presence of already perfect ones - the specified bend profile will not be obtained.

The bending order is a sequence of the form:

$$J=(J_1, J_2, \dots, J_n), \quad (3)$$

Where:

J – bending order function;

J_1, J_2, \dots, J_n – sequential numbers of places of bend of a part.

For example, the order of bending of a part can have two solutions:

$J=(1, 8, 4, 3, 6, 5, 7, 2)$ and $J^*=(1, 2, 5, 6, 8, 7, 3, 4)$

This problem is a special case of the traveling salesman problem, which generally has $n!$ solutions. To filter out the wrong decisions, in this case, there are technological limitations, derived geometrically and empirically confirmed and causing a given bend profile to be obtained. As an example, a part is shown that has several difficult places to calculate the correct bending order. The order of all technological transitions, calculated by an experienced process engineer, to obtain the part taken as an example and shown in Figure 1, is shown in Figure 2. As can be seen from the scan, it is not always possible to use the classical bending method according to the rule "from the periphery to the center", in this case, the bending order looks like this: $J = (1, 8, 4, 3, 6, 5, 7, 2)$, in this regard, it is necessary to enumerate various options to find the right solutions, by drawing several bending options to obtain a suitable details, which takes a lot of time and there is a high probability of miscalculation, which will entail a marriage during the manufacture of a part in the shop and a recalculation of all transitions. It may also be necessary to design bending equipment due to the impossibility of using the existing one. Manually enumerating all the options and finding the best one at the least time-consuming in the presence of 5 options or more (from 120 options) is not advisable and will take a lot of time.

To eliminate the human factor and significantly reduce the time for technological calculations, it is necessary to formulate an algorithm and derive the necessary formulas for drawing up a program for the automatic calculation of several variants of the bending transition sequences and checking each option for feasibility using the existing equipment.

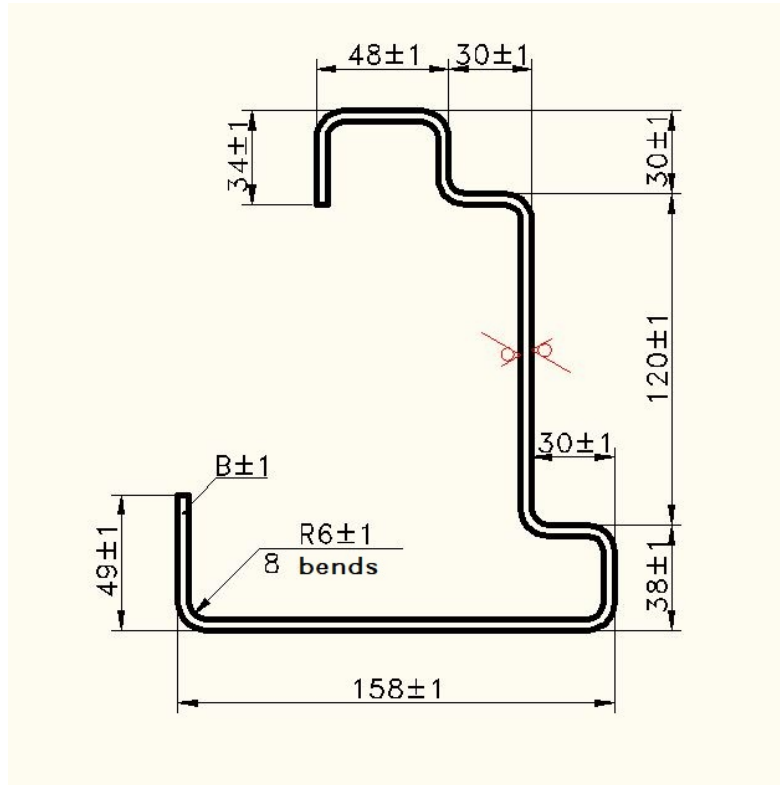


Fig. 1. Bending profile of a part.

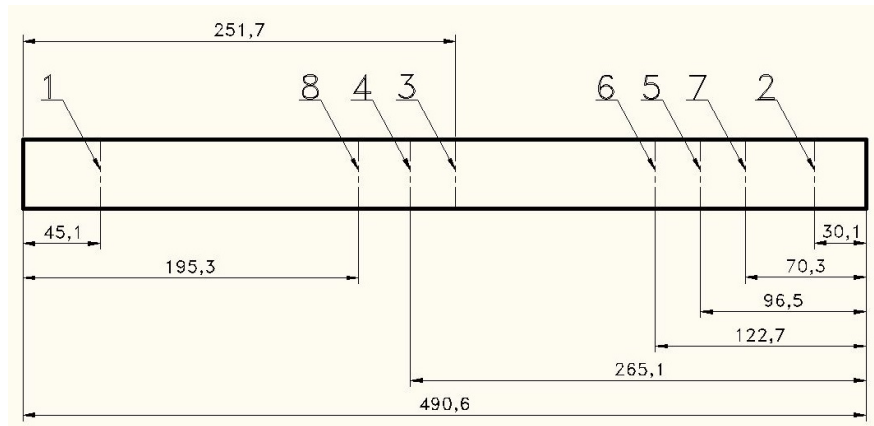


Fig. 2. Scheme of marking the involute of the part for bending indicating the bending sequence.

2 Materials and methods

To develop an algorithm for checking the bending orders for feasibility, it is necessary to determine and derive formulas required for calculations and checks for the feasibility of the subsequent bend in the presence of available bends after each transition.

List of formulas required for derivation:

- formula for calculating the length of the involute;
- formula for calculating the technological dimension required to set up the press for the next bend, based on the previous bend;
- formula for calculating all distances to each bend from both ends of the part (Figure 2);
- a formula for calculating the determination of the possibility of making a subsequent bend in the presence of already perfect bends (projection on the X-axis, Figures 3 and 4);
- determining the absence of conflicts between the punch and the part (Figure 5).

Calculating all values of $n!$ can be performed by any combinatorial permutation search algorithm without repetitions. In reality, in detail, the number of bends rarely exceeds 8 - a set of errors during bending and a shortage in the length of the sweep on the last bends affect, while the value of $n!$ with 8 bends and, accordingly, 9 shelves, the part will equal 362880 variants.

Formula for calculating the length of the unfolded when calculating a bent part with one bend:

$$L = (L_1 + L_2) - [2(\operatorname{tg}(\frac{\varphi_1}{2})(r_1 + s)) - \frac{\pi\varphi_1}{180}(r_1 + k_1s)] \quad (4)$$

If there are 2 bends in the part, the formula looks like this:

$$\begin{aligned} L = (L_1 + L_2) - [2(\operatorname{tg}(\frac{\varphi_1}{2})(r_1 + s)) - \frac{\pi\varphi_1}{180}(r_1 + k_1s)] + \\ + (L_3 - [2(\operatorname{tg}(\frac{\varphi_2}{2})(r_2 + s)) - \frac{\pi\varphi_2}{180}(r_2 + k_2s)]) \end{aligned} \quad (5)$$

If there are three or more bends in the part (in the general case), the formula looks like this:

$$\begin{aligned} \sum_{i=3}^n L_i = (L_1 + L_2) - [2(\operatorname{tg}(\frac{\varphi_1}{2})(r_1 + s)) - \frac{\pi\varphi_1}{180}(r_1 + k_1s)] + \\ + (L_i - [2(\operatorname{tg}(\frac{\varphi_{i-1}}{2})(r_{i-1} + s)) - \frac{\pi\varphi_{i-1}}{180}(r_{i-1} + k_{i-1}s)]) + \dots \\ \dots + (L_n - [2(\operatorname{tg}(\frac{\varphi_{n-1}}{2})(r_{n-1} + s)) - \frac{\pi\varphi_{n-1}}{180}(r_{n-1} + k_{n-1}s)]) \end{aligned} \quad (6)$$

The following formula is designed to calculate the unfolding of the part when specifying the lengths of the sides to the points of their intersection in the presence of dimensions of only straight sections, the formula will take on:

$$\sum_{i=3}^n L_i = (L_1 + L_2) + \left[\frac{\pi\varphi_1}{180} (r_1 + k_1s) \right] + \dots + (L_n + \left[\frac{\pi\varphi_n}{180} (r_n + k_ns) \right]) \quad (7)$$

The formula for calculating the distance from the end of the part to the first bend, as well as this formula is suitable for calculating the machine setup for making a bend after the previous bend has already been completed:

$$L = (L_n - (tg(\frac{\varphi_n}{2})(r_n + s))) + \left[\frac{\frac{\pi\varphi_n}{180} (r_n + k_ns)}{2} \right] \quad (8)$$

Formula for calculating the distance from the end to the next one after the extreme bend in the involute of the part:

$$L = (L_1 + L_2) - [2(tg(\frac{\varphi_1}{2})(r_1 + s)) - \frac{\pi\varphi_1}{180} (r_1 + k_1s)] - (tg(\frac{\varphi_2}{2})(r_2 + s)) + \left[\frac{\frac{\pi\varphi_2}{180} (r_2 + k_2s)}{2} \right] \quad (9)$$

The formula for calculating the distance from the end to the subsequent bends (not the extreme and not following the extreme) in the scan - if there are 5 bends or more (formula in general form):

$$\begin{aligned} \sum_{i=3}^n L_i = & (L_1 + L_2) - [2(tg(\frac{\varphi_1}{2})(r_1 + s)) - \frac{\pi\varphi_1}{180} (r_1 + k_1s)] + L_i - \\ & - [2(tg(\frac{\varphi_{i-1}}{2})(r_{i-1} + s)) - \frac{\pi\varphi_{i-1}}{180} (r_{i-1} + k_{i-1}s)] - (tg(\frac{\varphi_i}{2})(r_i + s)) + \\ & + \left[\frac{\frac{\pi\varphi_i}{180} (r_i + k_1s)}{2} \right] + \dots + (L_n - [2(tg(\frac{\varphi_{n-1}}{2})(r_{n-1} + s)) - \\ & - \frac{\pi\varphi_{n-1}}{180} (r_{n-1} + k_{n-1}s)] - (tg(\frac{\varphi_n}{2})(r_n + s)) + \left[\frac{\frac{\pi\varphi_n}{180} (r_n + k_ns)}{2} \right]) \end{aligned} \quad (10)$$

When jumping over several bends, it is necessary to calculate the distance to set up the machine for the next bend:

$$\begin{aligned}
L = & (L_{m-1} + L_m) - [2(\operatorname{tg}(\frac{\varphi_{m-1}}{2})(r_{m-1} + s)) - \frac{\pi\varphi_{m-1}}{180}(r_{m-1} + k_{m-1}s)] + \dots \\
& \dots + (L_n - [2(\operatorname{tg}(\frac{\varphi_{n-1}}{2})(r_{n-1} + s)) - \frac{\pi\varphi_{n-1}}{180}(r_{n-1} + k_{n-1}s)] - \\
& - (\operatorname{tg}(\frac{\varphi_n}{2})(r_n + s))) + \left[\frac{\frac{\pi\varphi_n}{180}(r_n + k_n s)}{2} \right],
\end{aligned} \tag{11}$$

Where:

$L_1; L_2; \dots; L_m; \dots; L_n$ – the length of the shelves of the bent part;

$\varphi_1; \varphi_2; \dots; \varphi_m; \dots; \varphi_n$ – bending angles between shelves L_1 and L_2 ; L_2 and L_3 ; L_{m-1} and L_m ; L_{n-1} and L_n respectively;

$r_1; r_2; \dots; r_m; \dots; r_n$ – internal bending radii between shelves L_1 and L_2 ; L_2 and L_3 ; L_{m-1} and L_m ; L_{n-1} and L_n respectively;

s – the thickness of the sheet material from which the part is made;

$k_1; k_2; \dots; k_m; \dots; k_n$ – the coefficients of displacement of the neutral layer (k-factor) in the places of bending between the straight sections L_1 and L_2 ; L_2 and L_3 ; L_{m-1} and L_m ; L_{n-1} and L_n respectively.

The formula for calculating the projection of the curved shelf on the X-axis (Figure 3):

$$L_x = (L_1 \cdot \cos \varphi_1) + (s \cdot \cos(90 - \varphi_1)) \tag{12}$$

The formula for calculating the projection of the curved flange on the Y axis:

$$L_y = L_1 \cdot \sin \varphi_1 \tag{13}$$

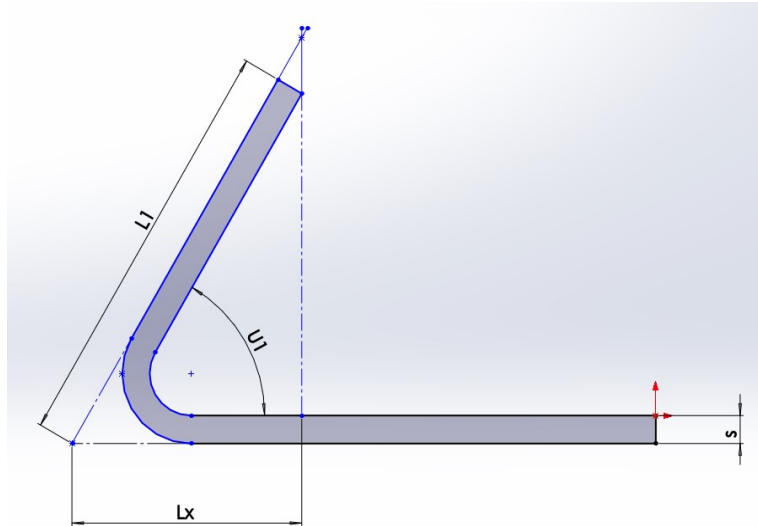


Fig. 3. Projection of curved shelves on the X axis.

When bending the next shelf (making the second bend sequentially) after the extreme shelf, the projection of the end (extreme point) onto the X axis will be calculated by the formula:

$$L_x = \left(\frac{L_2 \cdot \sin(\varphi_1)}{\sin(180 - \varphi_1 - \varphi_2)} \right) - \left[\frac{\left[\left(\frac{L_2 \cdot \sin(\varphi_1)}{\sin(180 - \varphi_1 - \varphi_2)} \right) \cdot \sin(\varphi_2) \right] - L_1}{\sin(\varphi_1)} \right] \cdot \sin(\varphi_1 + \varphi_2 - 90) \quad (14)$$

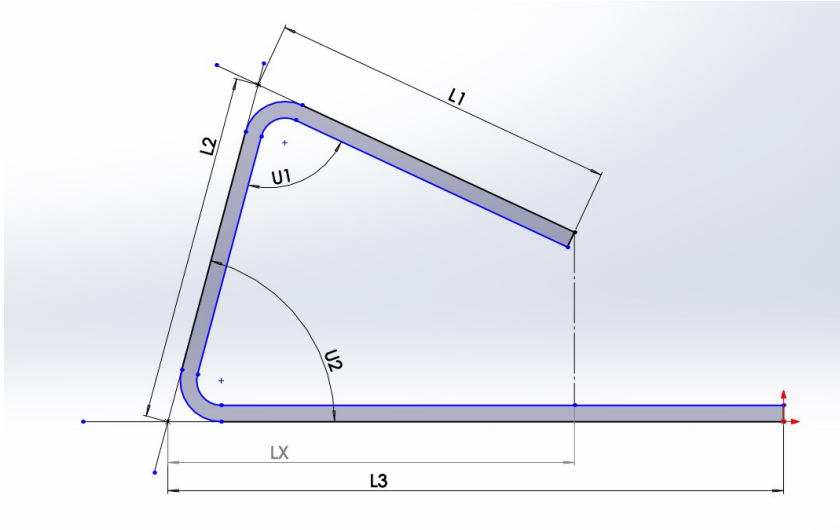


Fig. 4 - Projection of 2 curved shelves on the X axis.

Equation for checking the absence of conflicts between the workpiece and the tool when making the second bend:

$$\frac{\frac{B}{2}}{\left(\cos\left(90 - \frac{\varphi_2}{2}\right) \right)} \leq L_2 - \left[\frac{\left(\left[L_1 + \frac{s\left(\sin\left(\varphi_1 - \frac{\varphi_2}{2}\right)\right)}{\sin\left(90 - \varphi_1 + \frac{\varphi_2}{2}\right)} \right] \cdot \left[\sin\left(180 - \varphi_1 - \left(\frac{\varphi_2}{2}\right)\right) \right] \right)}{\sin\frac{\varphi_2}{2}} \right], \quad (15)$$

Where:

B- punch width, mm.

If the above condition is met, then the next bend at a given angle is possible (Figure 5).

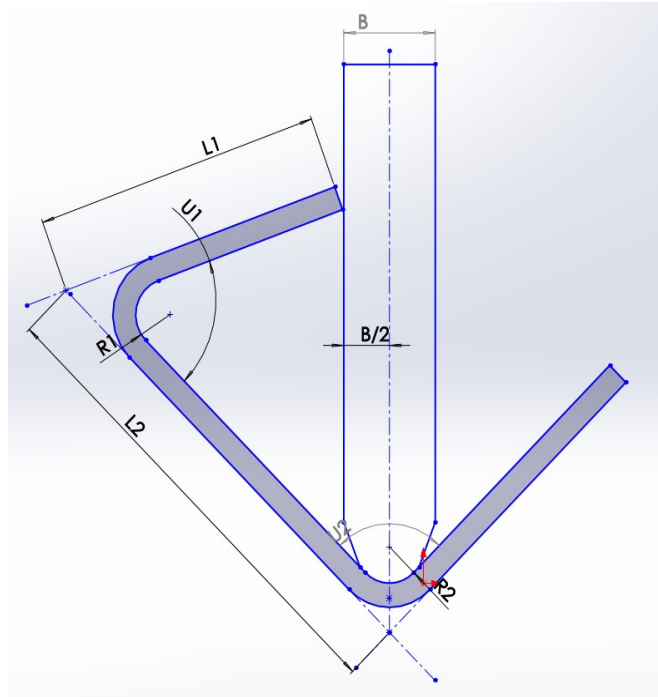


Fig. 5 - Limit location of the bend without a conflict between the workpiece and the tool.

The neutral layer displacement coefficient k (k-factor) depends on the ratio $\frac{r}{s}$ and is selected from the table 1.

Table 1. K-factor.

r/s	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
k	0.323	0.34	0.356	0.367	0.379	0.389	0.4	0.417	0.42
r/s	1	1.2	1.333	1.4	1.5	1.666	1.7	1.8	1.9
k	0.421	0.426	0.433	0.436	0.441	0.446	0.447	0.449	0.452
r/s	2	2.5	3	3.5	4	4.5	5	5.5	6
k	0.455	0.459	0.463	0.466	0.469	0.473	0.477	0.479	0.48
r/s	6.5	7	7.5	8	8.5	9	9.5	10 and more	
k	0.483	0.485	0.488	0.49	0.493	0.495	0.499	0.5	

3 Results and Discussion

The next step after deriving the required formulas is to determine and compose an algorithm for composing the bending order and an algorithm for checking the feasibility of each bend.

3.1. General algorithm for selecting the order of bending of a part with 3 or more bends:

- Calculation of the length of the sweep according to the formula (6) or (7) and all distances from each of the 2 ends of the part to each bend according to the formulas (8), (9), (10);
- Generation of flexible orders and checking each for feasibility (particular variants of the algorithms are given below);
- Revealing the presence of variable terms for calculating the total bending time for each of the possible options;
- Calculation of technological dimensions for each of the transitions for the least time-consuming bending option according to formulas (9), (10).

3.2. General rules for checking bends for satisfiability and simplified algorithms for special cases:

- If there is only one bend in the part, that is, $L_1 \neq 0$ and $L_2 \neq 0$ and $L_3 = 0$, bending is performed from either end of the part and, therefore, there are only two options for the order of bending, depending on the size L_1 or L_2 to be performed. , depending on the tolerance for the length of the shelf, the second dimension will be obtained automatically with the correct calculation of the involute.
- If there are two bends in the part, that is, $L_1 \neq 0$ and $L_2 \neq 0$ and $L_3 \neq 0$ and $L_4 = 0$, the possible number of options is 4 and the least time-consuming bending order is calculated by searching for shelves with the same length, when condition of equality of moduli of bending angles. If the values of the angles are not equal or not equal to the lengths of the shelves, then the order of bending will depend on the tolerances for the lengths of the shelves, first dimensions are made with narrower tolerance fields, and then with wider ones in ascending order. It is also necessary to check the feasibility of bends by the formula (15).
- When bending a part with three bends (the number of shelves is 4), in the classic version, bending starts from the extreme bends, then the middle bend is performed.

If $L_4 \neq 0$ and $L_5 = 0$, to: 'The length of shelf # 4 is not zero, and the 5th shelf is missing

If $L_1 = L_2$, then:

The order of bending will be: bending of the shelf L_4 , then L_1 , then L_2

Else If $L_1 = L_3$, then:

The order of bending will be: bending of the shelf L_4 , then L_1 , then L_3

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Else If  $L_4 = L_2$ , then:
    The order of bending will be: bending of the shelf  $L_1$ , then  $L_4$ , then
     $L_2$ 
Else If  $L_4 = L_3$ , then:
    The order of bending will be: bending of the shelf  $L_1$ , then  $L_4$ , then
     $L_3$ 
Else
    The order of bending will be: bending of the shelf  $L_1$ , then  $L_4$ , then
     $L_2$ 
End If

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In general, the bending of a part with three bends is possible, even in the presence of a closed contour of the part, with a part width of up to 300 mm and provided that special equipment is used.

3.3 As a rule, in the details, the extreme bends are the first to be made, located directly first from the ends of the part, to which they are parallel, and then, from the perfect bends, all the following bends are performed in turn in order from the edge to the center, but there are cases of exception (Figure 6a), when bending must be done from the middle to the edge (Figure 6b), otherwise the workpiece will conflict with the matrix.

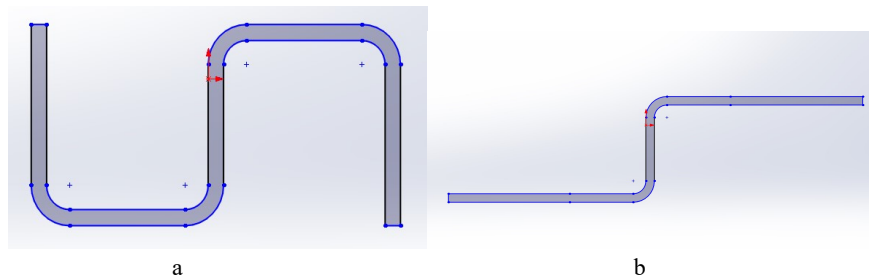


Fig. 6. The procedure for bending a profile of this form: a - finished part; b- first transition.

In this case, the bending order search algorithm will look like this:

$$\text{If } \varphi_{m-1} = \varphi_{m+1} = (-\varphi_{m+2}) = (-\varphi_{m+3}) \text{ and } L_m = L_{m+2} = L_{m+4} \quad (16)$$

Write to the array the bending order: $\varphi_{m+1}; \varphi_{m+2}; \varphi_m; \varphi_{m+3}$

Else

A general algorithm for searching and checking for the feasibility of bending options of the bending order is performed.

3.4 However, in cases where the end of the first bendable shelf is not at the level of the outer surface of the 4th bendable shelf, then bending "from edge to center" is possible provided that the blank can be placed in the required position on the die for the next bend. That is, the technological dimension should be greater than or equal to the sum of the length of the folded shelf number $m-2$ (when bending the shelf number m) and the distance from the edge of the matrix to the center of the strand (very often it is equal to half the width of the matrix):

$$L_{tech} = L_{m-2} + \frac{H_{matrix}}{2} \quad (17)$$

3.5 It is also necessary to take into account the direction of the bend and alternate bends, which must be done clockwise and counterclockwise. Therefore, when specifying the bending angles, it is necessary to indicate the bending direction with the + and - signs: "+" - counterclockwise and "-" - clockwise.

3.6 If 2 bends that are next to each other correspond to the condition: $\varphi_{n-1} > 0$ and $\varphi_n > 0$, then one of these bends must be performed at the last moment due to the fact that after it has been completed, adjacent bends will be impossible to perform without special equipment.

3.7 If 3 bends located next to each other correspond to the condition: $\varphi_{n-1} > 0$ and $\varphi_n > 0$ and $\varphi_{n+1} > 0$, then such a part cannot be bent by the universal method without the use of special equipment - a punch on cantilever suspensions. This punch can bend parts with a closed loop - when 3 or 4 bends occur in one direction: clockwise or counterclockwise, provided the length of the part is not more than ≈ 300 mm, depending on the thickness of the sheet metal due to low rigidity, and in due to this deflection of the punch.

In this regard, when calculating the order of bending of a part with 4 bends or more, it is necessary to introduce the above checks into the algorithm.

Below is an algorithm for fast selection of the search for one correct bending order, which is obtained from the thoughts of a process engineer. This algorithm allows you to get only one option and this option can be no less time consuming:

'n-number of shelves in the part, for example, if $n = 8$, then there are 8 shelves and 7 bends in the part.

For $i=1$ to $i=n-2$

If $\varphi_i > 0$ and $\varphi_{i+1} > 0$ and $\varphi_{i+2} > 0$, then

Message: "the part cannot be manufactured using this method"

Else:

$i=i+1$ Repeat check for each triple fold

For $i=1$ to $i=n-1$

If $L_i = L_n$ and $|\varphi_i| = |\varphi_{n-1}|$ then:

If $L_i = L_{i+1}$, and $\varphi_i = -\varphi_{i+1}$ and $L_n \neq L_{n-1}$, then:

Write to the array of the bend order: $\varphi_{n-1}; \varphi_i; \varphi_{i+1}$

If $L_n = L_{n-1}$ and $\varphi_{n-1} = -\varphi_{n-2}$ and $L_i \neq L_{i+1}$ then:

Write to the array of the bend order: $\varphi_i; \varphi_{n-2}; \varphi_{n-1}$

If $\varphi_i = \varphi_{i+1}$, then:

Write to the array of the bend order: $\varphi_i; \varphi_{n-1}; \varphi_{n-2}$

Else Write to the array of the bend order: $\varphi_{n-1}; \varphi_i$

$i=i+1$

n=n-1

Next, it is necessary to check the feasibility of subsequent bends according to the formula (15).

If one of the bends fails the check, then it is removed from the bend order array and the check order is repeated.

Repeat the cycle.

In the general case, the search for possible orders of bending is carried out using a combinatorial algorithm for searching for permutations without repetitions, then, when each option is found, the possibility of performing this order of bending is checked according to the algorithm presented above. If the result is positive, this order is remembered and the next order is generated.

After enumerating all possible options and filtering out unsuitable ones, it is necessary to determine the presence of variable components of the time function in each of the transitions, namely: the presence of the need to readjust the Ni machine and the need to change the tool Mi to complete this transition. The components of the time for setting the workpiece on the table Ti and the time for the tool stroke Vi can be conventionally taken as constant values for a given machine model, which do not depend on the number of bends in the part.

For the example given in the introduction (Figure 1), using a combinatorial algorithm and subsequent feasibility check, it was possible to find another variant of the bending order: J=(8, 6, 5, 7, 4, 3, 1, 2). With this order of bending, the number of permutations of the tool is equal to 1 - the initial installation of the tool on the press. The number of readjustments is 7. Let's calculate the T_{bend} value according to the formula (1):

$$t'_{bend} = (8 \cdot 3,15) + (7 \cdot 4,65) + (1 \cdot 95) + (8 \cdot 4,51) = 188,83c \approx 3,14 \text{ min} \quad (18)$$

Next, we will compare the obtained bending time with the time for which the existing bending order J=(1, 8, 4, 3, 6, 5, 7, 2), is performed, shown in Figure 2. With this bending order, the number of tool permutations is also 1, the number of changeovers is also 7.

$$t_{bend} = (8 \cdot 3,15) + (7 \cdot 4,65) + (1 \cdot 95) + (8 \cdot 4,51) = 188,83c \approx 3,14 \text{ min} \quad (19)$$

Based on this, we can say that in this case, both orders are flexible and there is no gain in time. And at the same time, the time spent on the selection of the bending order J was about 2 hours, and the selection of the bending order J 'took no more than 1 minute.

As you can see from the formula, the most time-consuming operation in bending is tool change. It takes an average of 95 seconds to change the punch, and 70 seconds to change the die. The calculation of the number of tool changes must also be taken into account in the check algorithm. Accordingly, such bending orders will be discontin-

ued, in which the tool change occurs only once in one direction without returning to the previous tool.

4 Conclusion

Let us formulate the main results obtained in this work:

1. A general optimization algorithm for finding the correct options for bending parts with parallel bends and identifying among the options found, options with a minimum time to complete all bends is formulated and described.

2. Basic formulas were derived for the theoretical calculation of technological dimensions:

- involute length;
- technological size required to set up the press for the next bend, based on the previous bend;
- all distances to each bend from both ends of the part;
- determining the possibility of making a subsequent bend in the presence of perfect (projection on the X axis);
- no conflict of punch and parts.

3. Algorithms for finding the order of bending of parts are formulated:

- with 1 bend;
- with 2 bends;
- with 3 bends;
- with 4 bends and more.

4. The resulting algorithms have been tested on several dozen details. During testing, not a single case of incorrect operation of the algorithms was revealed.

5. The creation of this optimization algorithm has significantly reduced the time for technological calculations when drawing up a technological process.

6. Thus, having received all the necessary formulas for calculations and algorithms in the future, it is possible to create an application capable of automating the technological process of calculations with graphical construction of bending transitions and setting the necessary technological dimensions based on AutoCAD and KOMPAS. In the future, it is planned to start developing this application with an interface understandable for any user to significantly speed up calculations and check the obtained algorithms, as well as to improve them.

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