Parametric modeling at defining technological axisymmetric flanging parameters from sheet blanks

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Abstract. The object of the research of the presented article is the internal axisymmetric cylindrical flanging. This work is intended to improve the quality and accelerate the development of technology for flanging round holes from sheet blanks and designing tooling by improving the accuracy of calculating the diameter of the flanging holes in the automated mode for constructing three-dimensional models of a blank and a flanged product. Formulas are proposed that increase the accuracy of calculating the diameter of the hole for flanging. The accuracy of calculating the diameter of the flange hole according to the proposed formulas is determined by comparing the mass of the workpiece with the mass of the flanged part. The algorithm for the automated construction of a sketch of a flanged part and the determination of technological parameters is implemented in KOMPAS-3D. The constructed models allow making changes to their parameters and to provide automatic presentation of the calculation results, as well as their correct graphical interpretation. A discussion of the results of the work allows drawing conclusions about the correctness of the proposed mathematical model and its applicability to the automated construction of three-dimensional models of flanged parts, which will simplify the development of technological and design documentation with a simultaneous increase in their accuracy and reduce the cost of preparing the production.

1. Introduction

When preparing the production of spatial products from sheet blanks, an important factor is the determination of the main technological parameters of the operation. They allow us to choose the product material and equipment, determine the dimensions of the tool and ultimately affect the quality of the product. This is especially true for small and medium enterprises, when the technologist and designer, and often the economist, are represented in one person. In this paper, the object of the study is the internal axisymmetric cylindrical flanging.

The main technological parameters of forming operations of sheet stamping include:
1. The dimensions of the workpiece.
2. The strain coefficients.
3. Power parameters of the operation.
4. Selection of the equipment.
An analysis of the literature [1-5] showed that the existing formulas for calculating the diameter of the flanging holes do not take into account the deformed state of the workpiece during shaping. As a result, as will be shown below, the dimensions of the products have significant deviations, which requires adjustment of the equipment for manufacturing of blanks.

**The aim of the work is:**
1. To increase the accuracy of calculating the diameter of the hole for flanging.
2. To create and to implement in a computer graphics editor a program for the automated construction of three-dimensional models of a workpiece and a flanged product and the calculation of the main technological parameters for shaping the selection process.

2. Materials and methods
The task to achieve this goal is to build models that allow making changes to their parameters and provide automatic presentation of calculation results and their correct graphical interpretation.

It is noted in the literature [1, 2] that the known formulas are applicable for parts with a flanging height not exceeding 0.3 of the diameter of the flanged hole. A simplified formula was proposed in paper [3] (as in bending operations) for calculating the hole diameter \( d_h \) in a flat workpiece

\[
d_h = D - 2(H - 0.43r_m - 0.72s),
\]

where \( D \) – flange median surface diameter, \( H \) – board height, \( r_m \) – spherical radius, \( s \) – initial metal thickness (Figure 1).

In work [2], a condition similar to that used for formula (1) for calculating the hole diameter was also taken \( d_h \)

\[
d_h = D - 0.57s - 1.14r_m - 2h,
\]

The thickness of the side edge \( s_{se} \) in the works [1-7] is determined from the ratio

\[
s_{se} = s\sqrt{K_f},
\]

where \( K_f \) – flanging ratio

\[
K_f = \frac{d_h}{D},
\]

where \( d_h \) – flange hole diameter, \( D \) – flange median surface diameter.

![Figure 1. Initial data for calculating the diameter of the flange hole.](image)

In the present work, on the basis of studies [6], the following distribution of the modules of the main logarithmic deformations was used to derive the formulas:

\[
|\varepsilon_1| \approx 2|\varepsilon_2| \approx 2|\varepsilon_3|,
\]

where the deformations are: \( \varepsilon_1 \) – периферический, \( \varepsilon_2 \) – along the generatrix, and \( \varepsilon_3 \) – by thickness.

Figure 2 is a practical design for determining the diameter of the flanging hole.
Figure 2. Scheme for calculating the diameter of the hole for flanging.

Where:
\[ D_f \] – median surface diameter, \( H \) – full side edge height,
\( h \) – the current height of the cylindrical section of the side edge;
\( s_0 \) – initial sheet thickness; \( r_m \) - spherical radius;
\( r \) – spherical radius of the middle surface; \( \rho \) – current radius;
\( \rho_0 \) – radius of the beginning of the cylindrical section; \( d\phi \) - angle increment;
\( s_{se} \) – the thickness of the side edge.

Having established the interconnection between the current values of the curved and cylindrical radiiuses and the corresponding sections of the flat ring in differential form, after transformations, integration, and approximations, we obtain a formula for determining the diameter of the flange hole

\[
d_h = 2\left(\frac{D_f}{2} + r\right)^{3/2} - \frac{3}{4} \pi \sqrt{\frac{D_f}{2}} \cdot \left(1 + \frac{0.175}{D_f}\right) \frac{\pi r D_f}{2} \frac{h}{D_f} \right)^{2/3}
\]

(6)

For the purpose of comparative evaluation, the diameters of the flanging holes were calculated using formulas (1-3) and (6). In this case, the following parameters were used in the calculations (see Figure 2):
- relative thickness - \( s_0/D_f \) within 2-5%;
- relative flange height – \( H/D_f \) within 15-25%;
- relative spherical radius – \( r_m/D_f \) within 10-20%.

The results showed that at a relative flanging height of up to 15-20%, the discrepancy between the calculation results between the known formulas and the proposed one (6) does not exceed 3%, and at 25% the discrepancy reaches 9%.

Modern CAD systems provide for complex automation of the control of parameters of geometric objects displayed in the form of three-dimensional models, drawings, and fragments using parametric modeling [7-11]. The task of creating a parametric model for determining the technological parameters of the flanging of round holes was solved using KOMPAS-3D.

The indicated model is built on the basis of the following components: sketch of the flanged part (Figure 3), geometric parameterization, formula (6), variable windows - Dimension variables and the Main section (Figure 4). Main Section variables do not directly control the parameters of the created sketch. They must be passed to the section Dimension Variables.
Figure 3. Sketch of the flanged detail.

Formula (6) in order to simplify its processing by the corresponding application module is divided into three components with assignment of symbols to them (the form of their records corresponds to the symbols in the variable window) - S1_1, S1_2 and S1_3 (see Figure 4):

\[ S1_1 = \frac{(D/2+r)^{3/2}}{2} \]  \hspace{1cm} (7)

\[ S1_2 = \frac{(3/4) \cdot \pi \cdot D/2 \cdot (1+0.175 \cdot (2 \cdot r)/D).}{8} \] \hspace{1cm} (8)

\[ S1_3 = \frac{(3/2) \cdot h \cdot D/2}{9} \]

Now the formula (6) has acquired the form (see. Figure 4)

\[ d_1 = \frac{2 \cdot (S1_1 - S1_2 - S1_3)^{2/3}}{10} \]

One of the main technological parameters is the force \( P \) necessary for flanging. It can be found approximately by the formula [4]:

\[ P = 1.5 \pi (D-d_1) s_0 \sigma_{ts} \] \hspace{1cm} (11)

where \( \sigma_{ts} \) – tensile strength.

Equipment strength \( P_e \), necessary for flanging, can be determined from the ratio [2]

\[ P_e = 1.25 \ldots 1.5 \cdot P \] \hspace{1cm} (12)

Flanging coefficient \( K_f \) is one of the factors determining the correctness of the selected parameters [1-6] (see formula 6)

\[ K_f = d_1/D_1. \] \hspace{1cm} (13)
Variable window part of the file "Sketch of a flanged part".

When changing the initial data in the Main section of the variable window, KOMPAS-3D automatically recalculates the required parameters and transfers it to the dimensional section of the window (see Figure 3), which in associative mode interprets them graphically in all forms of documents: fragments, drawings, three-dimensional models of both details and assembly units.

3. Results
A mathematical model is simulated that takes into account the deformed state of the workpiece (change in its thickness) during the flanging process and the condition of constant volume.

Based on the mathematical model, a formula is proposed for calculating the diameter of the flange hole.

A program was developed and implemented in KOMPAS-3D for the automated simulation of three-dimensional models of a workpiece and a flanged product and for the calculation of the main technological parameters for shaping the flanging process.

In order to assess the correctness of the used strain distribution scheme, three-dimensional models of the workpiece (Figure 5) and the flanged product (Figure 6) are simulated.
The accuracy of calculating the diameter of the flanging hole according to the proposed formula is determined by comparing the mass of the workpiece with the mass of the flanged part.

The mass difference between the workpiece and the product in this case was 0.37% (see Figure 5, 6). Thus, the accepted scheme of distribution of deformations during shaping allows to calculate with high accuracy the diameter of the hole for flanging. The mass difference according to the simulated three-dimensional models of the workpiece and the flanged product according to the existing formulas (1) and (2) is shown, for example, for the diameter $D = 101$ mm, $s = 4$ mm, $r_m = 5$ mm (see Figure 1) reaches 4.5%, and being recalculated in terms of the deformation zone it will be more than 10%.

4. Discussion and conclusions
1. The proposed formula, taking into account the deformed state of the workpiece (change in its thickness) during the flanging process and the condition of constant volume, shows the correctness of the simulated mathematical model, confirming the results of studies [6] and the ratio of deformations determining the thickness of the side edge [1-6].
2. The program developed and implemented in KOMPAS-3D allows automating the construction of three-dimensional models of a flanged part and a workpiece, as well as to determine the main technological parameters and, accordingly, the shape and size of the tooling.
3. The performed assessment of the correctness of the proposed formulas by comparing the masses of three-dimensional models of the workpiece and the flanged product using the KOMPAS-3D options shows that this method can be used to verify the correctness of the constructed model of the deformed state and for other similar cases.
4. Implementation of the results of the work will allow to simplify the development of technological and design documentation with a simultaneous increase in their accuracy, and to reduce the cost of preparation of production.
5. The work will be useful to students in technical educational institutions in the corresponding direction.

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