Toolset profiling for rotary draw bending of waveguides

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Abstract. The paper discusses the problem of bending quality of thin-walled structures of waveguides of rectangular cross section. Modern methods of solving the bending problems have been studied, from empirical relations to the use of artificial intelligence methods to achieve a minimum bending radius without product defects. It has been shown that the quality of the bend depends on a combination of many input parameters that are not always controllable. Even with the current level of computer performance, taking into account all these external factors, leads to the need to solve the probabilistic problem of a large number of variables, the unambiguous answer of which can currently only be given by approaches based on artificial intelligence. Despite the development and popularity of artificial intelligence methods, this way is still very expensive and long, so we propose a solution based on creating bending conditions that limit unwanted deformation and actually lead to die forming of the product. As a result, the resulting product and its quality parameters should be practically independent of various external factors and only the correctness of calculations and the accuracy of manufacturing the toolset of the pipe bending machine should be determined.

1 Introduction

The need to manufacture waveguides in large quantities is met with difficulties in ensuring conditions for constancy of the dimensions of the inner channel, especially for curved waveguides with a small bend radius. The increase in the production speed of curved waveguides is possible due to the use of automated CNC machines that use a progressive method of bending waveguides by rotary draw bending of the required radius. However, such machines are manufactured only in a universal design for bending pipes of circular cross section and do not meet the specific requirements for waveguides. Therefore, to ensure the quality of the bend, versatile scientific studies of the plastic bend process by rotary draw bending on such machines began to be carried out and work with new results appeared.

Plastic bending is a complex mathematical problem with nonlinearities, so there are not many analytical works on this topic, for example, [1-3]. Most modern researchers consider and solve the problem of plastic bending by numerical methods [4-6], usually it is a finite element method implemented in universal computer programs like Ansys, Abacus, etc. [7-8]. The resulting individual solutions allow you to vary various bend parameters and evaluate

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their impact on the result [9-10]. This approach is natural and the results obtained are very important for the development of both modeling and calculation methods and for taking into account the results obtained in practice. At the same time, this approach to date can be considered a dead end, since many results have already been obtained in this direction and many scientific papers have been written [11-12]. However, the problem of obtaining a quality product with a minimum bend radius remained.

The next step can be considered the development of complex calculations consisting of multi-stage iterative solutions, in which each individual task occupies a large number of computer resources and calculation time [13-14]. This approach certainly clarifies the calculated model to real data and allows taking into account, for example, the imperfection of the original geometry of the waveguide, the unevenness of mechanical properties in its volume (anisotropy), etc. Even with the development of computers, solving such problems requires the use of supercomputers and parallel computing technologies, which is not available for ordinary factories.

The development of artificial intelligence systems made logical the current stage of development of information support of the plastic bending process, in the form of development of databases for all performed bending processes [15]. This will allow you to summarize the initial data of the bend and its results for all sizes and shapes of the section and, as a result, predict with some probability the possibility of a qualitative bend for the required parameters. The development of this direction is still very expensive, and the resulting effect cannot yet be positively assessed. Judging by the pace of development of AI in other industries, a good result can be obtained only after a few years.

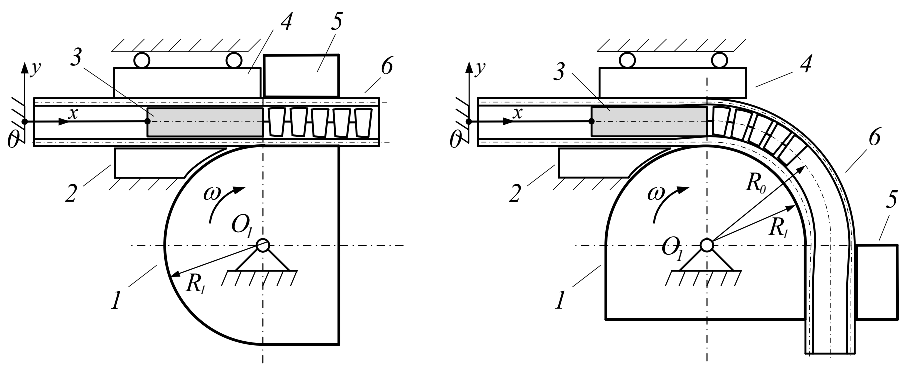
All considered methods for improving the quality of the bend are theoretical and are tied to the tooling, which remains unchanged all the time. However, there is another possible approach to solve the problem of plastic bending of the waveguide, which consists in the use of a new type of tooling, which, unlike the existing one, limits the deformation of the waveguide section in all directions due to the values of wall deformations calculated in the program during the plastic bending process, which does not allow the formation of undesirable wall deflections and defects in the form of "corrugations." This approach does not cancel, but complements the existing methods, which will now have to take into account the toolset used and the effect of it, including the previously proposed program [16].

2 Methods

Consider the bending of waveguides of rectangular cross section on a machine by rotary draw bending in terms of external influences and the resulting stress-strain state (Fig. 1, a). With the standard bending method, the waveguide is fixed in a rear clamp system consisting of a pressure die; a wiper die and a mandrel so that it can move only in the direction of its axis for feeding to the bending die. Such a fastening can be considered a fixed support with one degree of freedom, in the direction of the x axis. Front part of waveguide is rigidly pressed by clamp die to bending die and is wound on it in process of its rotation. In this case, the curved part of the waveguide changes the thickness of the outer and inner walls in accordance with the tension and compression stresses acting in them, as can be seen in Fig. 1, b. According to the Saint-Venant principle, such a change in wall thickness will occur at some distance from the bend area, which is shown in Fig. 1, b.

When using standard tooling, as in Fig. 1, the compression area will be the most dangerous, since an increase in the thickness of the inner wall will lead to pressure on the wiper die, mandrel and its core dies, which will lead to increased wear of these elements. Also, such a constrained compression of the inner plate, in which its thickening is prevented by the elements of the toolset, provokes the beginning of its stability loss. In a typical tooling, the bending stream has a rectangular shape with excessive gaps in width, which do not prevent the development of buckling of the entire section and the production of irreparable rejections.

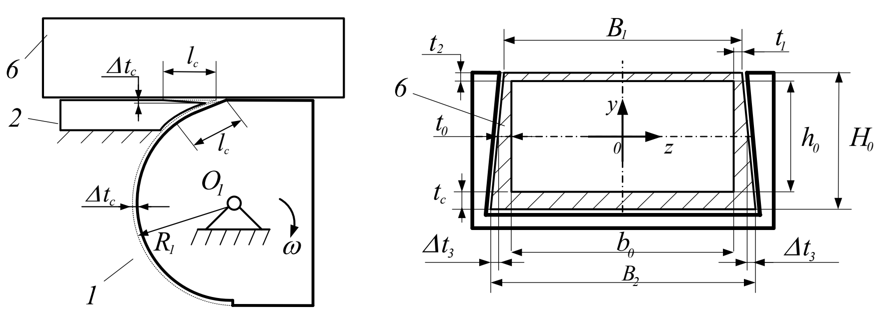
We propose a new type of toolset, which, unlike the existing one, limits the deformation of the waveguide section in all directions due to the values of wall deformations calculated in the program during the plastic bending process, which does not allow the formation of undesirable deflections of the walls and defects in the form of "corrugations". In this sense, the proposed approach is similar to constrained deformation in dies and takes full advantage of it, while eliminating the main disadvantage of the latter - low productivity, due to the use of a pipe bending machine. This idea was previously proposed by Fuchs [1], but was not further developed, probably due to the high cost of manufacturing special toolset and its narrow purpose. Each toolset will match only the specified section type, angle, and bend radius. However, for waveguides with strict requirements for geometric accuracy of the shape and dimensions of the inner section, this approach is the only acceptable.



a) starting position b) during bending

Fig. 1. Diagram of the process of waveguide plastic bending. 1 - bending die; 2 - wiper die; 3 - mandrel; 4 - pressure die; 5 - clamp die; 6 – waveguide.

Our method is to profile the bending die, bending groove and wiper die according to the change in the thickness of the inner wall, as shown in Fig. 2.



a) wiper die and bending die b) bending stream

Fig. 2. Profiling a toolset.

The change in wall thicknesses can be determined without resorting to complex calculations of the plastic stress-strain state of the waveguide during bending. To do this, it is enough to take into account two main hypotheses: constancy of the volume of material (incompressibility) and the Bernoulli flat section hypothesis. We also take into account that the loading of the waveguide during bending is actually not force, but deformation. That is, it bends to a given radius along a cylindrical circle and a given angle, which are the basic conditions for pure bending. The change in wall thicknesses will then not depend on the bending moment, but only on the change in the initial dimensions of the waveguide into a new curved shape with known geometry.

Using the approach [1], we obtain the following relationships for the thicknesses of the inner and side walls:

$$\Delta t_c = \sqrt{0.07 \cdot b_0^{\,2} + \frac{0.5 \cdot B_0 \cdot t_0 \cdot R_0}{R_1 + 0.5 t_0 + 0.13\left(R_0 - R_1 - t_0/2\right)\left(\dfrac{R_1 + t_0/2}{R_0}\right)^{0.2}}} - \frac{b_0}{3} - t_0, \tag{1}$$

$$\Delta t_3 = \sqrt{\frac{b_0^{\,2}}{4} + \frac{1.9 \cdot B_0 \cdot t_0 \cdot R_0}{R_1 + 0.5 t_0 + 0.15 \cdot H_0\left(\dfrac{R_1 + 0,5 t_0}{R_0}\right)^{0.6}}} + \frac{b_0}{4} - \frac{B_0}{2}, \tag{2}$$

$$l_c = \sqrt{B_0^2 + H_0^2}\,. \tag{3}$$

where the subscript zero denotes the original waveguide section dimensions.

The obtained expressions will make it possible to calculate the required parameters of tooling profiling and allow the walls of the waveguide to deform in the required direction to ensure the quality of the resulting product.

3 Discussion

The paper discusses the problem of ensuring the quality of waveguides of rectangular cross section during their bending and existing methods for achieving it. Most modern researchers consider and solve the problem of plastic bending by theoretical methods based on calculations of the given design of the machine and toolset, which have been practically unchanged for many years. An exception is the design of mandrels, in which the shape of the core dies, dimensions, etc. change, but due to the high cost, simple designs are used in practice.

We have proposed a new approach that proposes to change the geometry of the toolset so as to take into account the plastic deformation of the walls of the waveguide during the bending process and direct it to specially created areas. To do this, it is necessary to profile the wiper die, bending die and bending stream, making grooves in them to take up the thickening of the inner wall of the waveguide. At the same time, the bending stream takes the shape of a cone in its height, therefore, in order to extract the finished product, it will be necessary to provide for its prompt opening to ensure the continuity of the automated bending process on the pipe bending machine.

The manufacture of new shaped tooling is very expensive, therefore, in further work it is planned to perform 3D modeling of the tooling and waveguide and carry out comparative calculations by the finite element method. This will make it possible to assess the effect of tooling profiling and justify its application in practice.

4 Conclusion

The paper proposes a solution to the problem of obtaining a high-quality bend of thin-walled waveguides of rectangular cross section due to the use of a new type of toolset, which, unlike the existing one, limits the deformation of the waveguide section in all directions due to the calculated values of the expected wall deformations. The new geometry of the tooling does not allow undesirable deflections of the walls and defects in the form of "corrugations" and at the same time allows the geometry to change in only the required directions, while maintaining the size of the inner channel of the waveguide.

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