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Production of arc sheet elements by stepped bending method

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Abstract. The article considers the issues of obtaining thin-walled parts with arc-shaped elements for small devices and units in small-scale or single production using the principles of prototyping, which has recently been widely used to test and evaluate ideas at the earliest stage of development, and in some cases, to verify the functioning of a prototype device. Taking into account the requirements for the parts quality, the technology of stepped bending is chosen, which uses a set of consecutive *V*-shaped bends to obtain a given curvature of the billet. The basic principle of the multi-stage forming process is to replace the bending arc with a polygon, each side of which is a rectilinear section of sheet material of a given length, while bending the sheet metal using a small-radius punch. The accuracy of forming an arc segment using polylines depends on their number. The greater the number of bending steps, the smoother the profile is formed, but the bending process becomes more laborious and technically complex. Therefore, the technical and economic indicators of the process depend on correct choice of the number of steps. With this bending method, it is difficult to avoid a prismatic structure on the billet surface; in this case, the traces of step bends will be more noticeable on the inside of the bent sheet material compared to the outside. Using stepped bending technology, various metal parts of the prototype of the universal plasma low-temperature sterilizer of Plaster Med TeCo series were manufactured, which allows fast, safe and effective sterilization of a wide range of medical equipment. As an example, the use of stepped bending technology of a stainless steel sheet billet for the production of a thin-walled bumper for a sterilizer door is considered.

Keywords: thin-walled parts, arc-shaped elements, prototyping, stepped bending, sterilizer, stainless steel

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Изготовление дуговых листовых элементов методом ступенчатой гибки

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Аннотация. Рассмотрены вопросы получения тонкостенных деталей с дугообразными элементами для небольших аппаратов и приборов в условиях мелкосерийного или единичного производства с использованием принципов прототипирования, которое в последнее время широко используется для тестирования и оценки идей на самой ранней стадии разработки, а в некоторых случаях и для проверки функционирования прототипа устройства. С учетом требований, предъявляемых к качеству деталей, выбрана технология ступенчатой (пошаговой) гибки, в которой используется множество последовательных *V*-образных изгибов для получения заданной кривизны заготовки. Основной принцип многоступенчатого процесса формовки заключается в замене дуги изгиба многоугольником, каждая сторона которого представляет собой прямолинейный участок листового материала заданной длины, при этом гибка листового металла осуществляется с помощью пуансона малого радиуса. Точность формирования дугового сегмента с помощью полилиний зависит от их количества – чем больше число ступеней изгиба, тем более плавным получается формируемый профиль, но при этом процесс гибки становится более трудоемким и технически сложным. Поэтому от правильного выбора количества ступеней зависят технико-экономические показатели процесса. При таком способе гибки трудно избежать призматической структуры на поверхности заготовки, при этом следы от ступенчатых изгибов будут более заметны на внутренней стороне изгибаемого листового материала по сравнению с внешней стороной. С применением технологии ступенчатой гибки изготовлены различные металлические детали прототипа универсального плазменного низкотемпературного стерилизатора серии Пластер Мед ТеКо, который позволяет быстро, безопасно и эффективно стерилизовать широкий спектр медицинского оборудования. В качестве примера рассмотрено использование технологии ступенчатой гибки листовой заготовки из нержавеющей стали для изготовления тонкостенного бампера двери стерилизатора.

Ключевые слова: тонкостенные детали, дугообразные элементы, прототипирование, ступенчатая гибка, стерилизатор, нержавеющая сталь

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Introduction

Arc-shaped billets are a common type of sheet metal parts used in the fabrication of housings for various devices and products [1 – 3]. These billets feature variable geometries, and their processing is often more complex than that of conventional billets. In practice, two main forming methods are typically employed to manufacture billets with arc-shaped elements [4 – 6].

- Single-stage forming using a die and punch with profiles that match the required billet configuration. This method is generally applied to billets with complex shapes. Its advantages include high forming accuracy, a smooth and even billet surface, and the absence of surface defects. However, the cost of press tooling is relatively high, and its versatility is limited, making it most suitable for large-scale production. This approach is usually chosen when a single-stage process is required or when the surface quality of the billet is subject to stringent requirements.
- Multi-stage forming (stepped bending), which is based on approximating the arc by a series of straight-line segments. These segments can be formed using standard tools and equipment. The key advantage of this method lies in its flexibility: there is no need to manufacture custom dies and punches for each specific design. As a result, the production cost of billets is lower, and a high level of forming quality is achieved.

This article presents a stepped bending technology for forming the bending radius in thin-walled sheet metal parts and demonstrates its application in the fabrication of a specific arc-shaped billet.

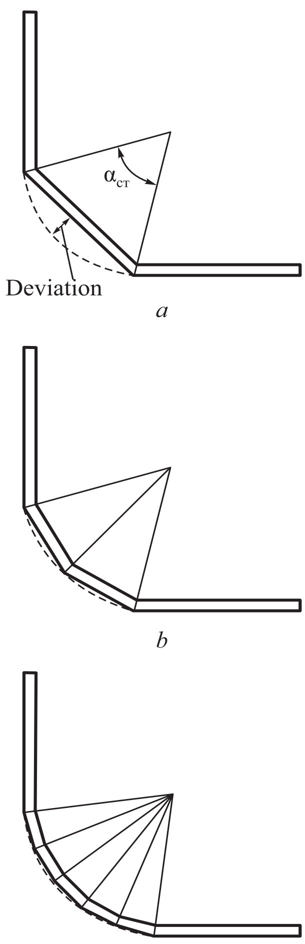

Fig. 1. Formation of bending radius of sheet material by stepped bending method with the number of steps $Z_{st} = 2$ (*a*), $Z_{st} = 3$ (*b*) and $Z_{st} = 6$ (*c*); dashed line shows the specified circular bending profile

Рис. 1. Формирование радиуса изгиба листового материала методом ступенчатой гибки при числе ступеней $Z_{ст} = 2$ (*a*), $Z_{ст} = 3$ (*b*) и $Z_{ст} = 6$ (*c*); штриховой линией показан заданный круговой профиль изгиба

Problem statement

The basic principle of the multi-stage forming process is to approximate the bending arc with a polygon, each side of which corresponds to a rectilinear section of sheet material of a given length (Fig. 1). In this method, bending is performed using a small-radius punch.

The accuracy of forming an arc segment using polylines clearly depends on the number of bending steps: the greater the number, the smoother the resulting profile. However, this also increases the labor intensity and technical complexity of the process. As a result, the technical and economic performance of the process depends on the correct choice of the number of steps. With this bending method, it is difficult to avoid a prismatic surface structure on the billet. It should also be noted that traces of stepped bends tend to be more pronounced on the inner side of the bent sheet metal than on the outer side.

Conducted research

Reference[1] examines the procedure for approximating a circular arc with polylines and calculating the bending angles of the segments, using as an example the steel part shown in Fig. 2. This part has an internal arc radius of $R = 350$ mm, a bending angle of $\alpha_{bend} = 120°$, and a plate thickness of $s = 5$ mm. Since the conditions for using the billet correspond to the characteristics of the multi-stage forming method, stepped bending was applied for its fabrication. Based on previous forming experience and the available forming tools, a punch with a tip radius of $r = 120$ mm.

To implement the multi-stage forming process, the curved segment (an arc with radius $R = 350$ mm) was divided into six segments (steps) represented by polylines. Practical experience in fabricating similar

[1] Shane W. Bump Bending for Large Bend Radius in Sheet Metal. Available at URL: https://www.machinemfg.com/bump-bending/ (Accessed 21.05.2025).

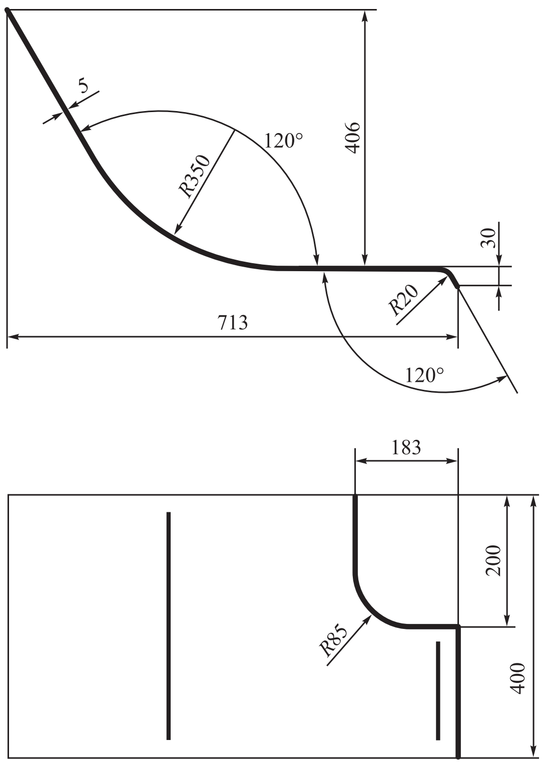

Fig. 2. Example of a part for segmentation of arc-shaped bend

Рис. 2. Пример детали для сегментации дугового изгиба

parts has shown that to achieve a smoother transition from the arc to the straight portion of the billet (i.e., at the ends of the curved segment), it is advisable to set the end step angles to half the value of the central segment angles. As shown in Fig. 3, the billet illustrated in Fig. 2 is formed by seven bending operations. The end (first and second) bend angles, corresponding to one step α_{st}, are 6°, while the remaining (central) bend angles are 12°. The total bending angle across all segments (steps) is approximately $\alpha_{st} \approx 170°$.

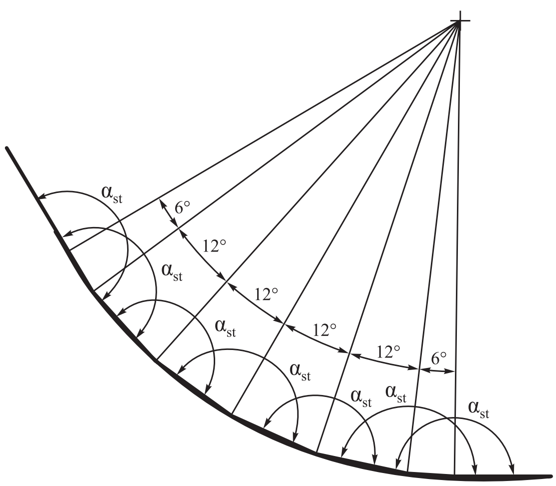

Fig. 3. Segmentation of arc-shape bend of polylines (7 bends)

Рис. 3. Сегментация дугового изгиба полилинній (семь изгибов)

An expanded view of the deformable billet with indication of bending lines is shown in Fig. 4, and its axonometric image is presented in Fig. 5.

Plasma-based technologies are widely used for sterilizing products in various sectors of the national economy, including medicine, pharmaceuticals, veterinary care, cosmetology, and the food industry. These technologies are valued for their versatility, enabling the sterilization of a wide range of items and materials [7 – 9]. In practical applications, the most common type of sterilizer uses an ionized gas as the active agent, generated under low pressure – so-called low-temperature plasma.

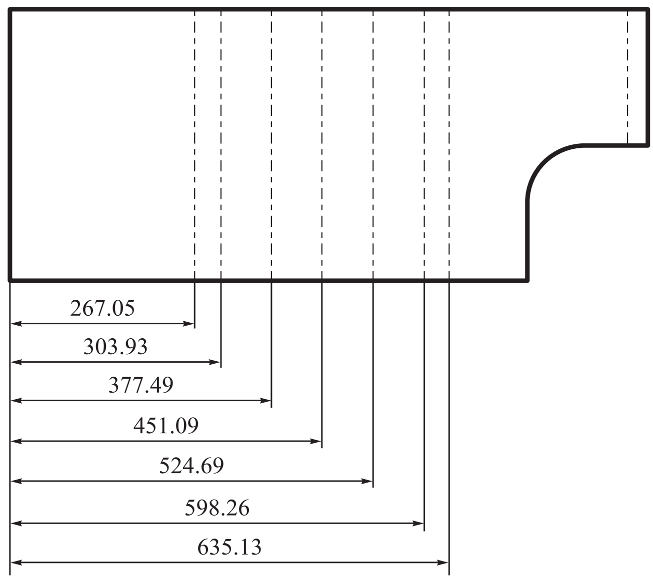

Fig. 4. Expanded view of the deformable billet with indication of bending lines

Рис. 4. Развернутый вид деформируемой заготовки с указанием линий изгиба

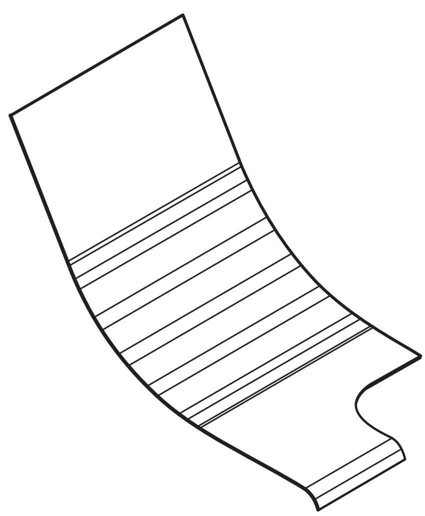

Fig. 5. Axonometric image of the deformable billet

Рис. 5. Аксонометрическое изображение деформируемой заготовки

Hydrogen peroxide is typically used as the sterilizing agent. It is introduced into the working vacuum chamber, where it acts on the treated items, disrupting the vital activity of microorganisms. Low-temperature plasma has virtually no adverse effect on structural materials, making it suitable for sterilizing products made from various materials, including metals, plastics, and textiles. Plasma technologies are particularly effective for sterilizing materials sensitive to high temperature and humidity, as well as instruments and devices with special coatings or painted surfaces [10 – 12].

Using stepped bending technology, various thin-walled parts were fabricated for a prototype of the universal low-temperature plasma sterilizer of the Plaster Med TeCo[2]. As an example of the application of stepped bending, this section considers the fabrication of an arc-shaped segment of the sterilizer door bumper. The axonometric image of the bumper is shown in Fig. 6, and its longitudinal section in Fig. 7. The final forming quality of the billet in this process depends on the number of bends and the spacing between them: the more steps used, the smoother the resulting surface. Given the hygienic requirements for the sterilizer, the bumper billet was made from 1 mm thick stainless steel grade 12Kh18N10T (GOST 5949–75).

Previous studies [13 – 15] provide formulas for calculating the bending angle of each step, as well as the deviation between the resulting stepped polyline profile and the target arc-shaped (circular) profile. Based on dimensionless (relative) parameters, a formula was derived for determining the step bending angle as a function of punch displacement. This forms the basis for selecting the number of bends needed to meet the technical requirements for the part's profile. It has been shown that for

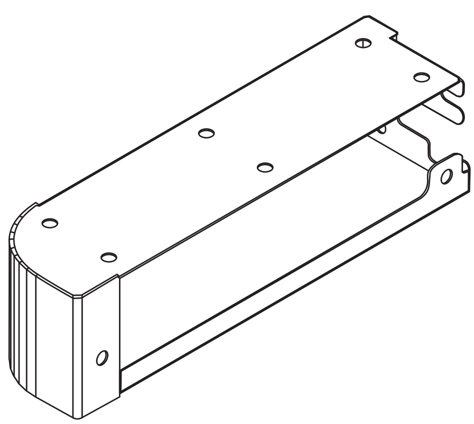

Fig. 6. Axonometric image of the sterilizer door bumper

Рис. 6. Аксонометрическое изображение бампера двери стерилизатора

[2] Low-temperature sterilizer Plaster Prime Med TeCo. Available at. URL: https://medteco.ru/product/sterilizatsiya/plazmennye-sterilizatory/plaster-praym/ (Accessed 21.05.2025).

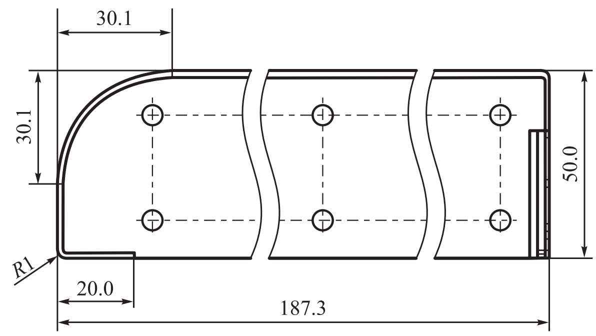

Fig. 7. Longitudinal section of the sterilizer door bumper drawing shown in Fig. 6

Рис. 7. Продольный разрез чертежа бампера двери стерилизатора, показанного на рис. 6

parts whose external dimensions must meet quality grade *h*12 (GOST 25346–2013), the number of steps should be $Z_{st} \geq 10$; for quality grade $h14 - Z_{st} \geq 6$.

In the present case, a slightly conservative value of $Z_{st} = 10$, was selected, resulting in a bending angle per step of $\alpha_{st} = 9°$. As noted earlier, to ensure a smooth transition from the arc to the rectilinear section of the billet (i.e., at the beginning and end of the arc-shaped segment), it is advisable to make the step angle in these regions half the angle of the central segments. Thus, at the end sections, the bending angle per step was set to $\alpha_{st} = 4.5°$. An expanded view of the deformed bumper billet with indication of bending lines is presented in Fig. 8.

Conclusions

The study addressed the fabrication of thin-walled parts with arc-shaped elements for small-scale or single production of devices and instruments using stepped bending technology, which involves a series of consecutive *V*-shaped bends to achieve the specified bending radius of the billet. Using this technology, various thin-walled parts were fabricated for a prototype of the universal low-temperature plasma sterilizer of the Plaster Med TeCo series. The practical application of this method was demonstrated using the example of forming an arc-shaped segment for the sterilizer door bumper.

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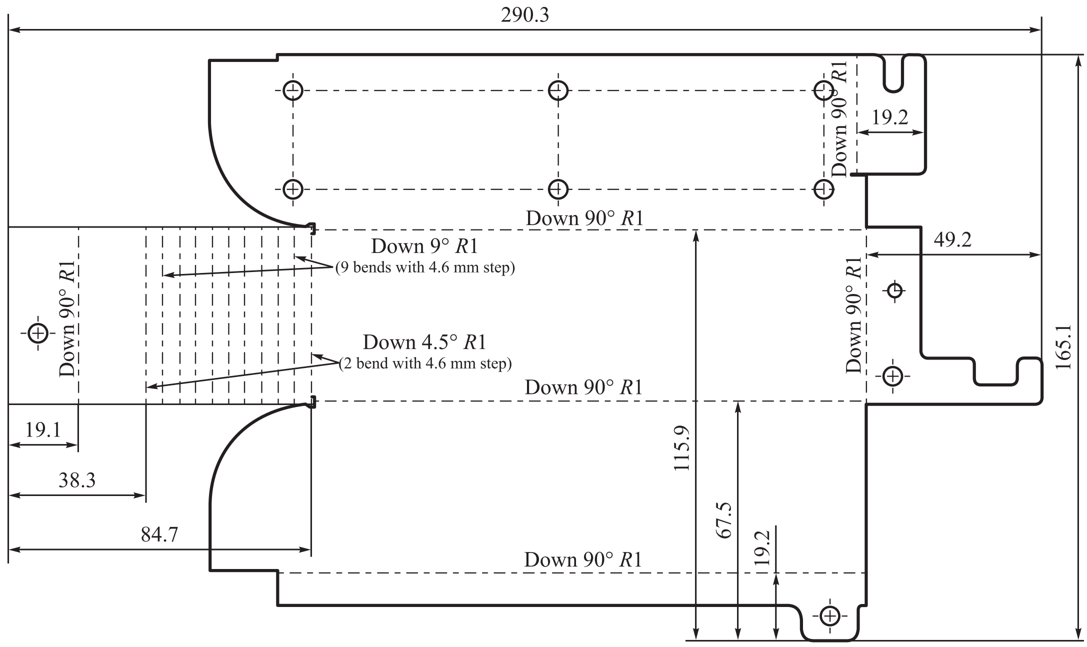

Fig. 8. Expanded view of the deformable billet of the sterilizer door bumper with indication of bending lines

Рис. 8. Развернутый вид деформируемой заготовки бампера двери стерилизатора с указанием линий изгиба

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Contribution of the Authors

A. O. Karfidov – formation of the article idea, technical justification of research objectives, setting goal and objective of research.
N. A. Chichenev – literary review, conceptualization, preparation of the text.
M. V. Vasil'ev – analysis and generalization of results.
O. N. Chicheneva – graphic design of results, final editing of the text.

Вклад авторов

А. О. Карфидов – идея работы, техническое обоснование задач исследования, определение цели и задачи исследования.
Н. А. Чиченев – поиск и анализ публикаций, входящих в наукометрические базы, формирование концепции статьи, подготовка текста.
М. В. Васильев – анализ и обобщение полученных результатов.
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