Device for automatic marking of billets for large diameter pipe bends

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The paper is devoted to description of the device for efficiency rise on conduction of marking operation during manufacture of large-size pipe bends. The existing method of marking applying and possibility of use of universal accessories, which displayed their low efficiency, were analyzed. The existing method of "lofting" is characterized by high labour intensity and low accuracy. Preliminary calculations of fabrication of universal accessories showed that it will be very expensive. The existing problem of low marking accuracy and high labour intensity of this process was solved owing to use of automation equipment. The device for measuring and marking, which is changeable accessories for industrial manipulating robot, was developed and described for this purpose. Architecture of the measuring and marking device and its elementary base, which allows to carry out automatic measuring of pipe bend billet, to conduct the required mathematical calculations and to apply marking, was described. The developed technique for measuring of pipe bend billet, allowing to determine the coordinates of basic points in the coordinate system of manipulating robot, was also described. Automation of transfer of the developed measuring and marking device was implemented via use of the industrial manipulating robot of Kuka Robotics company. Laboratorial example of this device was manufactured using the developed digital model. The experimental data that were presented in this paper displayed that accuracy of the laboratorial device corresponds to accuracy of marking applying via the existing technology and preliminary decrease of labour intensity was achieved about 50 %. The revealed disadvantages of construction of the laboratorial example of device were also described. Finally, the measures for improvement of accuracy of revealing the basic marking points were suggested; they include increase of a number of laser ranging devices and consequent calculation of coordinates on the base of average values of measuring data.
Key words: marking, robot, pipe bends, accuracy, labour intensity, accessories, automation, algorithm.
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1. Introduction

Automation of production processes in power engineering machine-building is a key factor for productivity rise of production facilities, as well as for improvement of processing accuracy and reducing of manufacturing rejects. Nevertheless, there was no sufficient attention paid to the problems of automatic pattern cutting of pipe billets. The researches were mainly focused on examination of pipes bending and the effects caused by this process [1, 2]. The paper considers the problem of carrying out marking of short-radius forged and welded bend billets, which concludes in complication of marking applying on bend billets for the following pattern cutting and boring of edges. According to the specifications to the bend drawing, a drift diameter of forged and welded bends manufactured by the works can be varied from 273 to 1,200 mm and wall thickness (e.g. for a bend with drift diameter 530 mm) is equal to 50 mm. This kind of bends is used in power engineering machine-building for building the contours of thermal and nuclear power stations.

The essence of technological process for manufacture of such forged and welded bends is concluded in tot forging of two bend halves made from sheet material, with their consequent welding. Then welding seam is subjected to abrasive treatment, ultrasonic control and heat treatment. As a rule, a forged and welded bend billet is fabricated as a segment with θ =200° with overlapping for edges processing. Afterwards, pattern cutting for the angles θ =45°; 60°; 90° or 180° via gas flame cutting is carrying out according to the specification, depending on the required order [3, 4]. Thus, up to 4 bend billets with the angle θ =45° can be obtained from one billet. In order to conduct pattern cutting of one complete billet, special technological operation called "lofting" is carried out. This operation is described in the work [5], it includes application of drawing dimensions for pattern cutting on a loft, i.e. the center of bend circumference is applied and then the half-lines are drawn from this center by required angles

Fig. 1. The process of "lofting" technological operation during marking of a bend billet

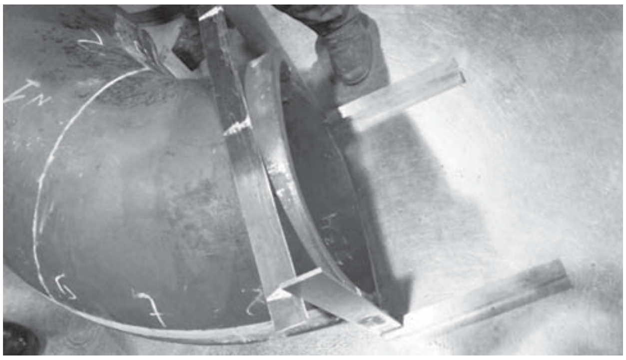

Fig. 2. Transfer of marking from a loft to a bend billet generatrix

using chalk, rope and other measuring tools (such as rulers, protractor, triangles). The next stage includes labour-intensive and thorough process of positioning a bend billet in correspondence with the preset points on a loft. It is important for an operator to provide positions of billets in such way, that perpendiculars, which were drawn down along generatrix of the internal radius in two points, coincide with theoretical distance on the half-lines measured on a loft.

The "lofting" process during marking of short-radius forged and welded bend billets is shown on the **Fig. 1**.

Based on the production experience, the technological operation "lofting" can be characterized as very labour-intensive and not producible. The process of marking application on a loft needs 15-20 min, positioning of large-size billet with weight about 150 kg also is rather labour-intensive process and requires definite skills and experience of the personnel, taking 15 min additionally. Usually commercial batches of bends include 40 pieces. It means that operator should wait for complete batch of billets before their marking in order to use once applied marking on a loft for a whole batch and not apply it for each separate billet. It accompanies by accumulation of billets and occupation of shop squares for their storage.

When providing "lofting" operation, operator applied three marks on external bend generatrix and then executed punching of these marks (**Fig. 2**).

The marks for pattern cutting by a gas torch cutter and for billet positioning in a boring machine tool for processing of edges before welding in the process of mounting are applied during marking application [6]. There are no special requirements on accuracy for marking before gas torch cutting, but there are strict requirements for marking before processing in a boring machine tool, because it has the effect on boring accuracy, and, respectively, on correct mounting implementation.

Positioning of a billet on the boring machine tool table is conducted in manual mode; it includes in billet positioning in such way, that the distance between marks and cutter bit was the same in three positions. In this case the plane of cutter bit rotation will be perpendicular to a pipe bend axis; in its turn, it guarantees absence of butt beat near pipe bend, which exceeds allowable limiting values.

Owing to the fact that marking is executed by one operator, and boring by another one, it can be difficult to identify the responsible person for waste metal, if any. Either marking is wrong, or billet positioning was incorrect. Waste metal caused by wrong boring achieves 15 % in average. Usually such waste metal can be corrected, i.e. such billet with defects is either subjected for pattern cutting again (for smaller angles) and forwarded to other orders, or the certificate of deviations is prepared and this billet is approved as ready product.

The aim of this work is creation of the special device for marking of pipe bends billets, providing this operation with minimal amount of manual work, higher accuracy and reduced basic technological operating time. This device will allow to rise efficiency of marking operation and to decrease amount of waste metal.

2. Materials and methods

The problem of technological operation of automatic marking of billets for large diameter pipe bends concludes in low automation level of marking process, large amount of manual work and hand measuring tools with low accuracy (such as rulers, protractor, triangles).

At the first glance, development of universal accessories to provide accurate marking seems to be rather actual. A prototype of such accessories includes loft, digital rulers, stands, lasers and other components. However, preliminary calculation of the cost of manufacture of these universal accessories for large-size details, such as pipe bends with drift diameter within the range 273-1,200 mm, displayed that its exceeded 8 mln. rubles. Preliminary evaluation of the cost of universal accessories was carried out on the base of market cost of its components, where checking plate is considered as the main mounting component with maximal cost. The cost of such checking plate with size 4,000x4,000 mm, with corresponding technological surfaces and mortises for mounting of peripheral equipment (digital rulers and sensors) was evaluated as 4 mln. rubles, based on the data of its producer – the Plant of special engineering "Mayak". External dimensions 4,000x4,000 mm are based on necessity to provide marking of billets from minimal size to maximal (within its dimension range) by universal marking tool. Preliminary digital designing of the universal unit model showed necessity of using a checking plate just with the above-mentioned size. It is not suitable to work with such large-size tool, because large marking equipment and large billets for marking will inevitably lead to beating each other during mounting, and it can worsen accuracy of tuning of universal accessories and, finally, to reduce marking accuracy.

To solve the problem, the following way is suggested.

1. Development of the new algorithm for measuring the actual bend billet, in order to determine its basic points and provide marking relating to these points.

2. Development of hardware of automatic device doth for measuring and marking.

3. Development of the method of automatic transfer of a measuring and marking device.

To realize this plan, the methods of mathematical and physical simulation were applied. Methodological base of quality evaluation for the new suggested technical solutions includes experimental methods for determination of dimensional links of the system. The industrial manipulating robot KR8 R1620 of Kuka Robotics company was used for laboratorial and stand experimental researches. The suggested methods and approaches during development of this technical solution are based on the main regulations of computer-aided engineering system (CAE system). Designing was conducted using up-to-date software RoboDK, Kompas 3D etc.

Analysis of accepting parameters of executive mechanisms and sensors of the designing device, which are accessories for manipulating robot, was evaluated using the beating chart in RoboDK medium. Analysis of beating during marking of the most widespread pipe bend type with diameter 530 mm displayed that the model of manipulating robot KR8 R1620 with loading capacity 8 kg meets the requirement of device transfer in the required positions without beating a billet. To provide marking of the whole dimension range of pipe bends up to 1,200 mm, the technical solution with top fixation of the manipulating robot, what allows to provide the required area of covering transfers of an executive device.

3. Results

The tasks for designing of the device for marking of pipe bends, which were formulated in the previous part of this article, were finalized in the hardware solution allowing to implement marking in automatic mode. In other words, a marking device should transfer automatically, according to the managing program. This condition can be realized using one of well-known industrial manipulating robots, which are widely presented in the market, e.g. industrial manipulating robots KR8 R1620 of Kuka Robotics company.

The second, more complicated problem is the question: "How can we explain to the robot in its coordinate system, where a pipe bend billet is locating relating to this robot"? I.e. we need to carry out preliminary measurement of pipe bend billet in the robotic coordinate system in order to find the basic points for providing transfer of marking tool relating to these points.

The third question covers the algorithm of transfer and mathematical calculation of the these points on the base of measured data.

3.1. Architecture of the measuring and marking device

The special device (**Fig. 3**), which is additional accessories for a manipulating robot, was designed for hardware realization of the formulated task.

The measuring and marking device, which is suggested for realization, unites laser radar *2*, burning laser *3* and microprocessor plate *4* inside split housing *1*. Providing of being the rays of burning laser *3* and laser radar *2* in one plane, with their rays crossing under the angle 90°, is the important condition to provide high accuracy of marking. This condition was realized owing to digital designing of housing *1* of the device and its consequent fabrication using additive technologies. In the case of sizing error in fabrication of housing *1* or errors in assembling of the device components, the software correction of calculating algorithms can be implemented. This correction can be provided via introduction of correcting coefficients which are determined during device calibration.

3.2. The algorithm of determination of the basic points in a pipe bend billet

Taking into account toroidal shape of a bend billet, it is necessary to determine x and y coordinates of the O point, which is included in the tor axis, in the robotic coordinates system in order to provide bend marking into segments with preset dimensions. The coordinate z of the O point is not so important for calculations and can be preset in manual mode, because transfer of a marking device in the x and y plane is mostly important. If we know the coordinates of the O point, it will be not difficult to set the coordinates for transfer of a marking tool.

The calculating scheme is presented on the **Fig. 4**. Analysis of this scheme shows that it is necessary to calculate x and y coordinates of the points K_1 and K_2 for making transfer programming, while the coordinate z is set based on calculation of sum of bend diameter, height of measuring and marking device (specially designed accessories for a manipulating robot) and safety distance 150 mm.

Calculating of the coordinated of the O point is realized due to measuring the internal bend curve by a laser radar. Microprocessor plate *4* (see Fig. 3), based on the feedback, provides an order to a robot management system for transfer of the housing *1* (see Fig. 3) with laser radar 2 (see Fig. 3) from one of the setting parallel rods *2* (see Fig. 4) to another with preset step value *t*. In this case microprocessor plate of the device saves in its memory the data of measured distance during each step iteration, and at the same time obtains the data about laser radar coordinates at each measuring step due to feedback with a robot management system [7-9]. Thus, the data about length *L* of the base of measuring segment, which is equal to product of number of steps on their length t, as well as height *H* of this segment, which is equal to a module of difference between the minimal and maximal values of measuring distance for laser radar emitter, are saved in memory of microprocessor plate of the device. Additionally, the data about coordinates of laser radar position at each preset measuring step are fixed.

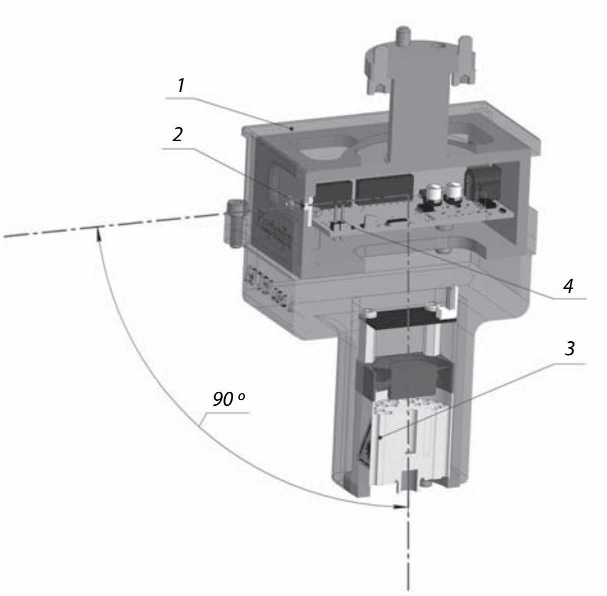

Fig. 3. Longitudinal section of the model of measuring and marking device

Numerical value of the radius curve can be calculated from the expression (1):

$$R = \frac{\left(\frac{L}{2}\right)^2 + H^2}{2H}, \quad (1)$$

where L is the length of the base of measuring and H is the height of this segment.

Knowing the radius of internal circumference and coordinates of laser radar location in the middle of L length, it is easy to determine the coordinate of $O_{(x,\ y,\ z)}$ point via elementary algebraic calculations. Then the coordinates of the points K_1 and K_2 are calculated depending on the required marking angle and dimensions of a bend billet.

3.3. Automation of the measuring and marking process

It was mentioned before that the industrial manipulating robot of Kuka Robotics company was chosen for implementation of automatic transfer of the measuring and marking device. The robot series was selected depending on dimensions of marking bends, it should provide both free running

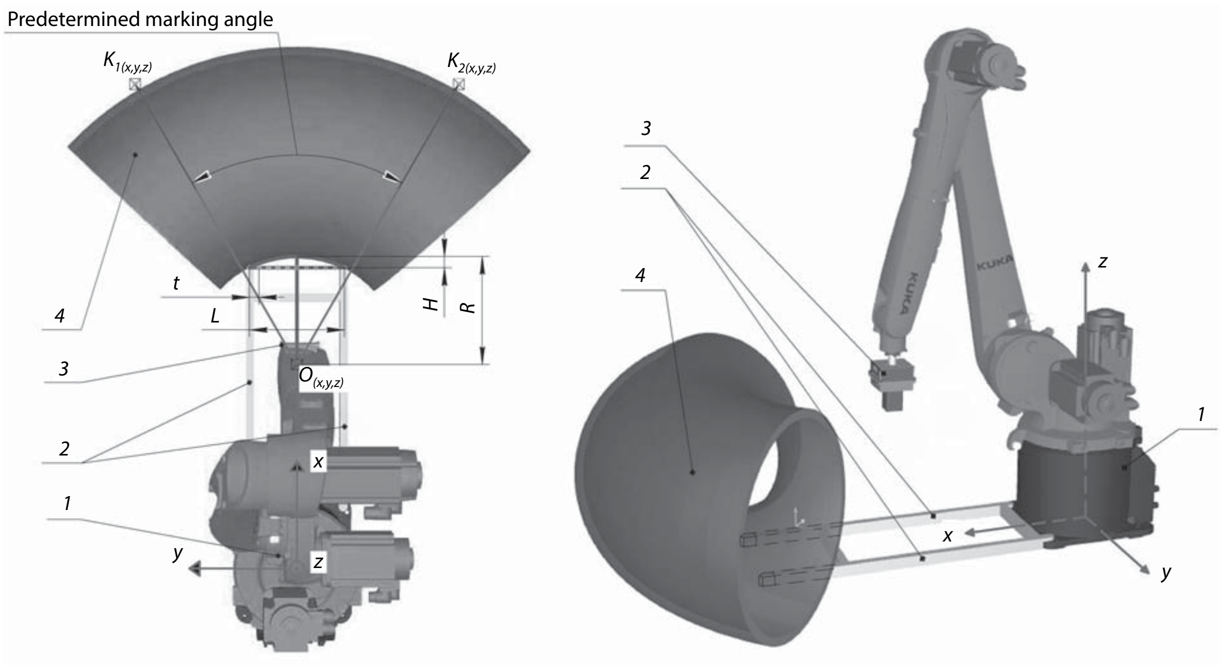

Fig. 4. The scheme for calculation of marking points:
1 — manipulating robot; 2 — setting parallel rods; 3 — measuring and marking device; 4 — marking bend billet

of this device in the measuring area and its transfer to the marking points.

The software that was used for development of this device, such as RoboDK, allow to program transfer and management logics of the device via standard code management lines as well as via code inscription with Python language. It opens opportunities for conduction of mathematical calculations and organization of data exchange with peripheral devices [10, 11]. However, realization of mathematical calculations using the remedies of peripheral microprocessor plate was not random. The device is considered as changeable accessories, and using manipulating robots can differ in their architecture, software version, electronics, what can make it difficult for final customer to adjust and operate the device [12]. The robot management system serves only for device transfer within the coordinate space and sending of the values of these coordinates to a microprocessor plate of this device. This plate, in its turn, is responsible for commands for measuring, scanning and recording of the measuring results, for scanning and recording of location coordinates (which are obtained from the robot management system), for conduction of mathematical calculations and generation of the management signal for manipulating robot transfer [13]. Additionally, the microprocessor plate of the device also realizes burning laser switching-on and switching-off [14].

3.4. Description of laboratorial researches

Laboratorial example of the device, which was assembled on the industrial manipulating robot KR8 R1620 of Kuka Robotics company, is presented on the **Fig. 5**.

Laboratorial tests were directed on comparison of theoretical marking points and points obtained during measurements. Theoretical marking points were applied on a loft using the industrial manipulating robot of Kuka Robotics company and its possibilities for discrete transfer step-by-step of its mounted accessories. Then a sheet of bended metal, corresponding to bend diameter 530 mm, was set by these points. A metal sheet imitated internal surface of bend generatrix. The aim of the experiment concluded in comparison of the coordinates of marking points, which were obtained during measurements and calculations, and theoretical coordinates, which were applied in manual mode.

Laser radar ToF10120 with certified measuring accuracy ±0.5 mm was used in conducted laboratorial tests. Small-power burning laser from a teaching robot Dobot Magican was also used. The measurements were conducted on a metal sheet with curvature radius corresponded to a bend with diameter 530 mm, which was previously bent and coloured.

4. Conclusions

The experiment displayed that deviation between the coordinates of theoretical point *O* and the coordinates obtained during measurements is within 1 mm. It should be noted that repeatable accuracy of the results of determination of the coordinates of theoretical point *O* was constant. The measuring step t was chosen equal to 1 mm in this experiment and transfer was implemented in manual mode. I.e. time for damping of inertial oscillations was held before the measurement, after each transfer of the device. To provide operation in automatic mode, manufacture of more rigid device construction is required. At the same time, operation in automatic mode allowed to reduce time for marking conduction by 50 % relating to time spent for lofting.

A burning laser, which was used in the experiment, had not sufficient capacity for marking application on metallic surface; additionally, it was characterized by small focusing distance, but it was sufficient for the experimental purposes. It is recommended to use high-power lasers 100W in industrial scale, like those used for marking of metallic products.

Controlled drawing dimensions L and L1 for a bend with diameter 530 mm have ultimate dimensional deviations -2/+3 mm and respectively 5 mm tolerance. In general, the achieved marking accuracy obtained during the experiment corresponds to accuracy obtained via "lofting" method.

According to the designing documentation of the manufacturer, the most strict tolerance for controlled dimensions

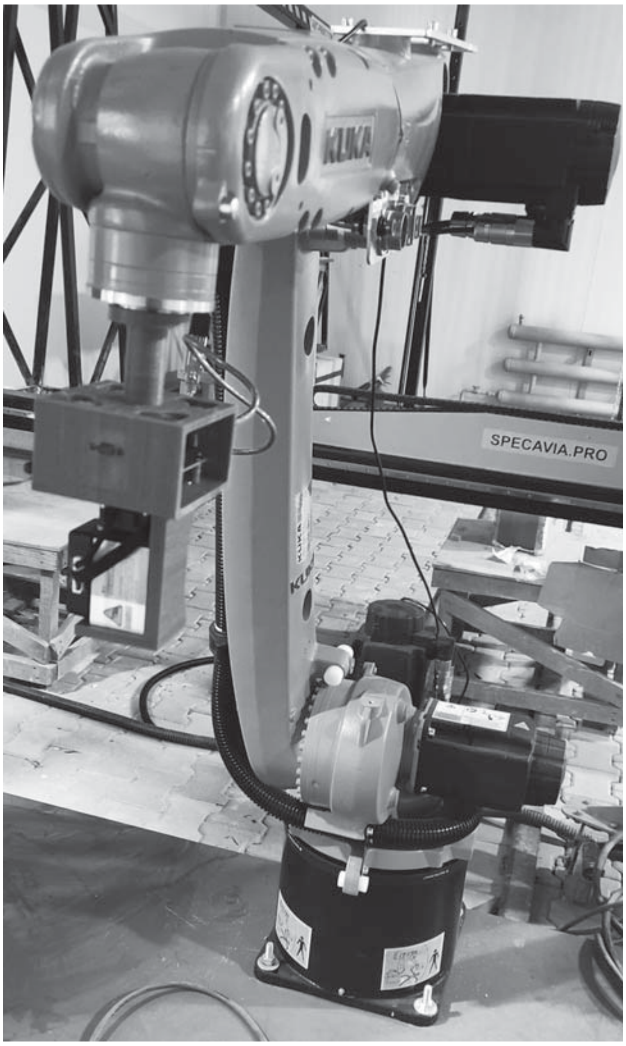

Fig. 5. Laboratorial example of the device for measuring and martking, which was assembled on the industrial manipulating robot KR8 R1620 of Kuka Robotics company

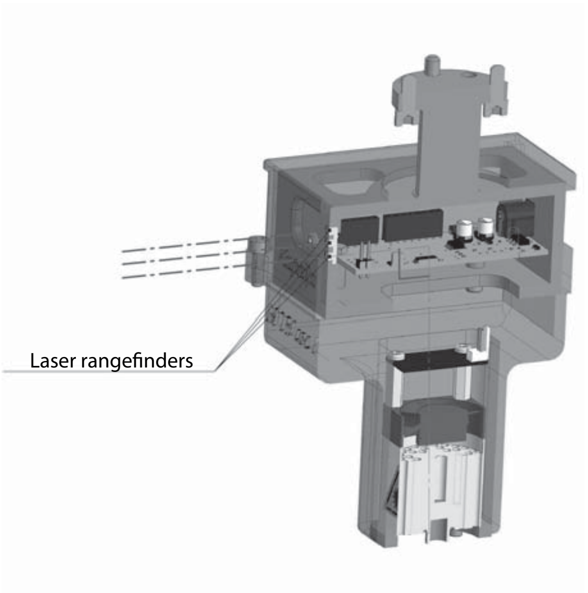

Fig. 6. Measuring and marking device with 3 laser radars

is applied for bends with minimal diameter 273 mm and is equal to 2 mm. Accuracy of tolerance for manufactured bends with maximal diameter 1,200 mm is equal to 8 mm. Thereby, achieved making accuracy 1 mm, provided by the device, allows to guarantee marking accuracy within the required tolerance for the whole dimension range of manufactured products.

5. Final statement

Thereby, the measuring and marking device for a manipulating robot has been developed to solve the problem of increasing accuracy of bend billets marking and reducing labour intensity of marking operation. This device allows to implement automatic measurement of a bend billet and to determine the coordinate of the concealed base – the *O* point on the bend axis.

It is necessary to improve measuring accuracy in the process of further optimization of this device. It can be achieved due to increase of number of measuring elements with simultaneous measurement, or due to increase of iterations of repeated measurements. For example, the device for this purpose can be equipped with several laser radars, which will provide simultaneous measurement in several planes on different z coordinates (**Fig. 6**).

Construction of this device, which is presented on the Fig. 6, provides determination of the average value of the point *O* coordinates on the base of measuring and calculating data for this point, which were obtained by each laser radar in different planes for *z* coordinate. It leads to improvement of measuring accuracy and, respectively, to increase of marking accuracy.

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