A method of determination of average plane of taps of pipes by triangulation method using an anthropomorphic robot

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Abstract. Nowadays there are various manufacture methods of pipe taps. One of the most laborious operations during manufacture is a marking of pipe taps for subsequent machining. Work layout operations are performed using special tool ware and outfit. These operations are performed manually and it leads to the decrease in accuracy and to the increase of laboriousness. The authors suggest the method of determination of the latent base of pipe tap (average plane) using an anthropomorphic robot. The results of research would help to make the virtual calculation of tool position of the anthropomorphic robot for marking and to generate the robot trajectory. Ultimately, such research would also decrease laboriousness and increase accuracy of marking operation. Materials and methods. The authors supposed to use latent base, namely the average plane of the pipe tap as a measuring base. The robot is calibrated from the base plane placement and chooses the shortest circular arc by comparative approach. Therefore, such shortest arc would form the average plane. The authors carry out the determination of the curve line length by the triangulation method using the interferometer. Results. The result of the research is the technology development for determination of latent base in the average plane form. Discussion and conclusion. The proposed method of latent bases determination of pipe tap would allow making the automated system of marking of pipe taps. Moreover, such method would help to reduce time of performing operations as well as to decrease the manufacture laboriousness on the following stage of technological process.

1. Introduction
The development of technology of construction production and processing of raw materials lead to the need to use more powerful machines and equipment that have complex hydraulic and pneumatic systems transporting a working or process fluid, as well as high-pressure gas. It is often required to design and manufacture a trunk with a complex configuration and spatial position, operating under high pressure and at high temperatures. For this purpose, rigid and flexible pipelines are used. The first includes welded structures of pipes and fittings to the second high-pressure hoses. High-pressure flexible hoses are convenient in the production of machines and are used on moving blocks and aggregates when transferring hydraulic fluid or gas over short distances, but their price is high due to the complexity of the production technology and materials used. In the case when the machine or complex has a stationary structure and are located on the area at a considerable distance from each other and from the pumping station, the process liquid or gas has a high temperature, then it is more expedient to use pipelines made in the form of a welded construction of pipes [2, 3, 4, 5]. Cement concrete and asphalt concrete plants can belong to such technological complexes. An asphalt concrete
plant (ACP) is a complex of machines, buildings and structures for the preparation of asphalt and bitumen mineral mixes, which are used in the construction and repair of asphalt pavement. One of the main components of ACP complexes is bitumen facilities. The bitumen plant consists of a system of tanks and piping networks that provide unloading of bitumen, storage, dehydration, heating to operating temperature and subsequent supply of asphalt mixing plants to the dosing devices. The development of a method of fully or partially automating the process of marking and subsequent processing of pipeline elements will reduce the labor intensity and improve the accuracy of installation of ACP bitumen lines during their construction and repair, as well as other technological systems used in a road construction.

In the production of connecting parts of pipelines installed for branching, turns, transitions to a different diameter, various tees, transitions, taps, etc. are used. Such products are primarily divided by the cross-section indicator into small ones from 5 to 102 mm, average ones from 102 to 426 mm and large - over 426mm. In addition, they are classified according to such indicators as the material of manufacture, cross-sectional profile, size, connection method and type of insulation [4, 9]. Steel pipes and fittings are divided into seam and seamless. According to the specifics of production, they can be welded, stamped, welded-stamped, forged, forged-drilled, etc. [5]. As a rule, for marking the pipes and fittings of small diameter, universal technological equipment is used, which allows marking and then machining the pipeline elements, maintaining the required angles, eliminating the face runout of the ends of the processed pipes and fittings. In addition, the connection technology itself by welding on such dimensions of sections allows one to compensate the trimming errors and radial runout and obtain a reliable connection. Another situation arises when the cross section of the pipeline is of medium and large size, then non-perpendicularity of the pipe end to its axis can lead to a significant end runout beyond the tolerance limits. So for example the design of the steeply curved branch of type 3D (R ≈ 1.5 DN), the marking of which can be done by the proposed method is regulated by the interstate standard GOST 17375-2001 (ISO 3419-81). A conditional passage of such taps according to the standard is in the range from 15 to 1000 mm [4, 9, 10, 12].

A marking is the transfer to the pipe from the working drawing of the dimensions necessary for the manufacture of a part or element of the pipeline. To do this, use the production methods. According to GOST 2.419-68, under the term “plating” is meant such a production method in which parts are made, marked or controlled on the basis of assembly drawings, templates, layouts, battens, sketches and drawings taken from the mould loft. The mould loft is a platform laid out with cast-iron or steel plates, on which the contour of the blank is drawn in its natural size, which is transferred to the blank with the use of measuring tools. A markup is an important and demanding operation that requires careful execution. The pipe layer-scriber should be able to read the drawings and have a spatial representation of the product shown in the drawing; know the geometric constructions and draw the reamers, know the necessary allowances for the further processing of pipes and parts and take them into account when establishing the marking dimensions; economical use of materials, as much as possible using trimming pipes and other materials [4, 8]. The marking operations are performed by geometrically constructing marking lines and signs, for which portable measuring tools and templates are used. The marking requires: steel tape measure, ruler, square, compass, caliper, caliper, gauge, protractor, level, scoop, center punch, hammer, and templates [15]. The markup and control are carried out according to the procedure given in RD 03-606-03 [9], the list of instruments used in those marking or control operations is also given there. To the accuracy of the measurement requirements are presented in table1.

According to the passport of the anthropomorphic robot [13, 17], the accuracy of movement of the working body is governed by such an indicator as repeatability and is 0.08 mm. This means that the working body of an anthropomorphic robot is able to move to the same point with a maximum error of 0.08 mm. Such an indicator of repeatability is achieved through the use of servo drives with feedback in the design of the robot. Considering the fact that the minimum permissible measurement error for sizes up to 0.5 mm is 0.1 mm, it can be judged that using an anthropomorphic robot as an aggregate
for measuring and marking the products covered by [9] will meet the requirements of regulatory documentation.

Table 1. Requirements performed for accuracy measurements

| Measured value range, mm | Measurement error, mm |
|--------------------------|-----------------------|
| Up to 0,5                | 0,1                   |
| From the 0,5 to 1,0      | 0,2                   |
| » 1,0 » 1,5             | 0,3                   |
| » 1,5 » 2,5             | 0,4                   |
| » 2,5 » 4,0             | 0,5                   |
| » 4,0 » 6,0             | 0,6                   |
| » 6,0 » 10,0            | 0,8                   |
| » 10,0                  | 1,0                   |

The places marking pipes painted with chalk paint mixed with liquid glass or wood glue. On 1 liter of water take 120 g of chalk and 7 g of wood glue. Risks are applied on the painted surface with a scribe, after which they are staked to prevent it from being erased. In order to avoid significant errors when applying lines to the product it is prohibited to use chalk [9]. In the case of automation of the marking process, the operation of coring can be replaced by laser engraving, by installing a laser engraver as the working body of an anthropomorphic robot. For marking pipes with a conditional passage from 100 to 500 mm into sectors, welded bends are used with a hinge device (Figure 1). It consists of a prism 1, which is installed on the pipe, a hinged lever 4, mounted on the protractor 2. At the end of the lever there is a pencil 3 or scoop. The protractor can be rotated 90 ° in both directions. This device can also mark the ends of the equal pass fitting [8].

**Figure 1.** Swivel device for marking pipes: 1 – prism, 2 – protractor, 3 – pencil, 4 – swivel lever

The special universal compass (figure 2) is used for the marking of pipe holes for fittings. This compass allows to mark holes at any angle of the fitting. The compass is fixed on the pipe, then set the required angle by turning of the marking tool. When marking of the pipe insets, placed at an angle to the pipe axis, the compass set to the desired angle. With this compass mark patterns, outlining the contours of the holes on the paper, cardboard, sheet metal, screwed on the pipe of the desired diameter [8, 9].

It’s often applied the patterns for the marking of the cut lines of the fitting butt – ends for the inset, the sectors the half sectors of the welded pipe taps. The sizes for the pattern production must be indicated in the working drawings. In the case of an absence of the working drawings, the sizes are found graphically [15].

The described methods of marking of the pipes and the fittings, special equipment, pattern marking etc. are the methods of high labor intensity as well as the marking operation and operation of the
pattern production. Because of this highly skilled workers are required. A wide range of size produced by enterprises is not covered [16].

The development of method, which allows fully or particularly automate the marking and the following processing of the pipeline elements is important and actual task which has a great practical utility for the enterprises engaged in the production of lifting and transport, construction machinery [5, 18] and equipment, complexes for the processing of raw materials and power engineering.

![Figure 2](image).

**Figure 2.** Universal compass for marking holes on pipes: 1 – scriber, 2 – mounting foot, 3 – movable leg, 4 – pipe

In the item 5.1 of the RD 03–606–03 [9] it’s indicated that «The use of other devices of the visual and measurement control is allowed subject to the availability of the corresponding instructions and methods of their application. This means that the developers of the instruction [9] in spite of the quite complete list of the measurement tools that covers a wide field of the described marking operations provide the appearance of the new tools and methods, which allow to solve the same tasks with less laboriousness and greater accuracy.

To solve a number of the tasks, which allow to make automated marking of the steeply curved stamped – welded pipe taps, the authors propose to use the robotic system based on an anthropomorphic robot and the theory of the triangulation method of measurement.

The triangulation control method based on the calculation of the desired distance using the aspect ratio of the triangle and known system parameters [12]. It allows to measure the relative change in distance from the sensor to the controlled object, as well as the absolute value of the distance. The controlled distance may be from the microns to hundreds and thousands of meters.

The one of the main task of this scientific work is determine the placement of the pipe tap middle plane and put the axis of the robot working tool in this plane.

2. Materials and methods

Because the pipe taps are the stamped – welded constructions (Figure 3) of the various diameter and radius depending on a standard size, it’s necessary, that the method of coordinates determination of the measurement base of the pipe tap and the following centering of the working tool was universal and didn’t require additional technological equipment at changing of the pipe tap standard size.

Due to the high mass and imperfection of the surface of the workpiece, obtained by the stamping, the process of the workpiece set on the measurement base, on the lower guiding surface of the pipe tap causes considerable difficulties. Our method suggests to use the latent base (the middle plane of the pipe tap Figure 4) as a measurement base. The middle plane of the pipe tap is a plane that passes through the less inner guiding line and through the largest outer guiding line.
From the description of the middle plane of the pipe tap it follows that the robotic system should be able to position itself, that the axis of the measurement tool placed in the plane that paralleled to the middle plane of the pipe tap, i.e. to set the desired angle of the turning of the sensor ray relative to the some theoretical segment AB of the OXY plane (in the Figure 4 coincides with the average plane). The distance D from the lower guideline of the pipe tap to the point A and the distance C from the lower guideline of the pipe tap to the point B must be the same.

**Figure 3.** Marking of the pipe taps in real manufacturing conditions

**Figure 4.** Theoretical placement of the average plane of the pipe tap
Figure 5. Coordinate systems of the anthropomorphic robot: a – coordinate systems of the robot, b – coordinate systems in determining the average plane of the pipe tap

Next, it’s necessary to consider the coordinate systems of the anthropomorphic robot in order to understand how we can define the placement of the theoretical segment AB by a program method. The coordinate systems of the anthropomorphic robot is shown in the Figure 5

As we can see in the figure 5, there are following coordinate systems:

1. ROBROOT – the ROBROOT coordinate system is a Cartesian coordinate system, which is always located at the robot base. It defines the position of the robot relative to the WORLD coordinate system;
2. WORLD – the WORLD coordinate system is a permanently defined Cartesian coordinate system. It is the root coordinate system for the ROBROOT and BASE coordinate systems;
3. BASE – the BASE coordinate system is a Cartesian coordinate system that defines the position of the workpiece. It is relative to the WORLD coordinate system;
4. FLANGE – is a Cartesian coordinate system of the flange, it’s fixed in the flange of the robot, it is a reference point for the coordinate system TOOL;
5. TOOL – the BASE coordinate system is a Cartesian coordinate system that defines the position of the workpiece. It is relative to the WORLD coordinate system [13].

Figure 6. The scheme of measurement of the arc length
The system of the robot allows to determine the coordinate system BASE [7], for example, by specifying three points and the direction of the X axis on base plane, on which the workpiece is placed. The points are specified by manual calibration. Considering, that the base plane is a calibrated with the high degree of flatness, and the plane XOY of the system coordinate BASE is defined and known to the robot, we can easily set a condition when the interferometer [14] will move in the plane, which is paralleled to the base plane, i.e. without changing the coordinates along the axis Z. The start point A and the finish point B are set manually [6, 19].

The essence of the technique is an iteration determination of the arc length using laser interferometer measurement system, which moves along the segment AB by the robot and measures the distances to the object with the given pitch without changing the coordinates along the axis Z, and the tool axis must be perpendicular to the segment AB. It’s known that the length of the arc \( l \) is the limit, to which the perimeter of the broken line inscribed in this arc tends, when the number of chain links grows indefinitely, and the longest link length \( L \) tends to zero, or mathematically:

\[
l = \lim_{\max \Delta L_i \to 0} \left\{ \sum_{i=1}^{n} \Delta L_i \right\}.
\]  

(1)

It is clear from the definition that it’s necessary to measure the distance to the object with the pitch, write the points coordinates then calculate the lengths of the obtained segments and sum them. In this way we obtain approximate length of arc. The accuracy of the arc length calculation depends on the pitch of the measurements [1]. The measurement scheme is shown in the figure 6.

Knowing the measurement step (given by the operator) i.e. the value of the triangle leg we can calculate the value of the second leg as a difference of the length from the interferometer to the pipe tap surface, according to the Pythagorean theorem we can calculate the value of the hypotenuse, i.e. the length of the \( \Delta L_i \). Having obtained the sum of all the links after the measurement, we will know the length of the arc in a particular position (inclination angle) of the measuring instrument relative to the segment AB. By the iteration comparison of the arc length with the various values of the inclination angles of the measurement tool, we can calculate the position at which the arc length will be minimal, i.e. it will draw a circle close to the correct one (figure 7). This means that the tool axis will be placed in the plane which is paralleled to the average plane of the pipe tap. If the arc length is greater than the minimum possible, then the tool axis intersects the plane, and the arc will have a parabolic shape (Figure 8), its length will obviously be greater than the length of a regular circle (Figure 7).

![Diagram of the measurement setup](image)

**Figure 7.** The arc of inner radius of the pipe tap in the case of location of tool axis in the plane, which is paralleled to the average plane of the pipe tap
3. Conclusions
The results of the work are the developed method for iteratively determining the coordinates of the position of the hidden measurement base in the form of the median plane of the retraction workpiece by comparing the arc lengths at different positions (inclination) of the measuring tool relative to some specified theoretical segment AB and then comparing the arc lengths when the coordinates change along the Z axis.

The developed method will allow to make the marking of the pipe taps by the geometric calculation of the coordinates desired points relative to the placement of the average plane of the pipe tap, as well as will allow to mark the workpiece by the core, laser or the cutter.

4. Discussion and conclusion
Improving the method of the management of the construction manipulator workflow in the form of the anthropomorphic robot based on the developed method of determination of the average plane of the workpieces. This method will allow to significantly reduce the complexity of operation, to increase accuracy and reduce the time of marking of the pipe taps, for example at the assembly or construction works of the bitumen pipelines of the coating plants.

In the course of the research work it was developed the method of the coordinates determination of the average plane of the tap pipe. We described the process of the calculation the arc length by the triangulation method, the algorithm of the determination of the incidence angle of the pipe tap average plane using the anthropomorphic robot was compiled.

The reduction of the operations complexity of the marking of the coating plants pipelines is provided by a replacing of manual labor of workman, who makes mark on the base plane and transfers this marking from the base plane to the workpiece, with the process of the automated obtaining of the workpiece profile using the triangulation measurement method, algorithmic calculation of the workpiece latent base coordinates and automated marking the workpiece by the construction manipulator.

The increase of the accuracy of the marking is provided due to the working body positioning accuracy of the anthropomorphic robot which has servo with the feedback and laser sensors, which allows to provide working body positioning with the accuracy up to 0,08 mm. Such accuracy provides absolute compliance with the requirements of the normative documents [9] of the measurement accuracy at the marking operations. For example, the minimum permissible measurement error for the sizes up to 0,5
mm is 0.1 mm. The authors suggest that the accuracy increase of the workpiece marking provides absence of the defect on the following grooving operations and installation of pipelines elements of the coating plants. The results of the work are the developed method for iteratively determining the coordinates of the position of the hidden measurement base in the form of the median plane of the retraction workpiece by comparing the arc lengths at different positions (inclination) of the measuring tool relative to some specified theoretical segment AB and then comparing the arc lengths when the coordinates change along the Z axis.

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