Theoretical basis for measuring and compensating for deviations of ship pipelines at the design and installation stages

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Abstract. In this article, the author considered the problem of increasing technological efficiency of the pipelines of ship systems at the design stage and presented the way of manufacturing and assembling of ship pipelines without measuring at the ship. For that, the author created the theoretical basis for measuring and compensating for deviations of ship pipelines at the design and installation stages. There has been done the analysis of standardized deviations controlled in the process of pipe manufacturing according to the drawings. The article reveals the reasons making inappropriate the technology of manufacturing pipes according to the project documentation by the method of bending. The reasons of deviation development and amount of deflection from structural dimensions that arise during the pipe manufacturing have been determined.

1. Introduction

At the current level of computer technology, tracing a pipeline without touching neighbouring structures is a simple and solved task. The problem is that pipes made according to drawings, like any part and product of mechanical engineering, have standardized dimensional tolerances [1-4]. However, in the process of laying pipes in any routing program, these tolerances are not examined. As a result, the projected gaps between routes or with neighbouring structures are minimal (they can reach "0", only negative gaps are controlled). In other words, when assigning clearances, the tolerances for manufacturing pipes according to the drawings are not examined in the design trace, which leads to the inability to install the route, since the pipes rest against neighbouring pipelines or structures [5].

Such designing led enterprises to refuse to manufacture pipes according to design drawings, although all documentation is transmitted electronically. Design organizations are satisfied with this situation, since factory workers have no complaints about tracing. For these reasons, the problem of manufacturing pipes in reserve has not yet been resolved [6-8].

2. Theoretical basis for measuring deviations arising in the manufacture of ship pipelines

The process of obtaining pipes of various configurations is associated with the execution of pipes cutting and bending. It is precisely on the accuracy of the indicated operations that the possible deviations of the pipe coordinate dimensions depend. Pipe bending is performed on pipe bending machines with manual, semi-automatic and automatic control. Manual control machines are machines where the process of fixing the pipe in the machine is carried out manually with clamping screws. With semi-automatic control, the process of fixing the pipe is automated. With automatic control, both the fixing process and the pipe bending processes are performed automatically by dialling the appropriate numbers
on the machine’s remote control, or using software storage media. Pipe bending is based on a specific and constant geometric relationship between the position of the pipe bending machine nodes and the pipe axis. In this case, the plane of the camber pipe 2 lies in the plane of the bending disk 1. The bending disk is rotated in one direction.

The bending process, in general, consists of three main operations:

- promotion (setting the size before bending);
- bending;
- rotation (setting the angle between the planes of the camber).

Obtaining pipes of various configurations is associated with performing a set of operations, the errors of which affect the deviations of the coordinate sizes of the pipes (figure 1).

![Figure 1. Measurement deviations in cutting, bending, and rotating operations.](attachment:image)

The idea of obtaining a pipe configuration by performing promotion, bending, turning, and cutting is the fundamental idea of the hypothesis about the relationship between configuration and deviations of coordinate pipe sizes.

The papers [9-12] present the mathematical basis for determining deviations in the coordinate dimensions of pipes.

3. Measurement of coordinate dimensions of pipe ends

The coordinate dimensions of the ends of the pipes were measured after bending on a special tool (plate, square, millimetre ruler), the measurement accuracy was 0.5 mm. According to the results of measurements, tables were compiled for pipes with 1, 2, 3 cambers (Tab. 1). A comparative analysis of the tables confirms that the configuration of the pipes and its deviations is determined not only by the number of cambers, but also by their relative position.

Comparison of actual and calculated deviations of the coordinate dimensions of pipes confirms with a sufficient degree of accuracy the correctness of the developed mathematical relations.

| № pipe | Coordinate dimension of pipes | Actual deviations | Estimated deviations |
|--------|-------------------------------|-------------------|---------------------|
|        | mm                            | mm                | mm                  |
| 1      | Estimated                     | Actual            |                     |
|        | \(x\) 1200                   | \(X\) 1202        | \(\Delta X\) 2.0    | \(\Delta x\) 1.5   |
|        | \(y\) 450                    | \(Y\) 445         | \(\Delta Y\) -5.0   | \(\Delta y\) -4.9  |
| 2      | \(x\) 720                    | \(X\) 719         | \(\Delta X\) -1.0   | \(\Delta x\) -1.1  |
|        | \(y\) 400                    | \(Y\) 403         | \(\Delta Y\) 3.0    | \(\Delta y\) 3.2   |
4. Analysis of deviations in structural dimensions that occur during the manufacture and installation of pipes

In the course of the research, the release of the documentation was analyzed with the tolerances that occur during the process of manufacturing pipes according to the drawings, which allows the installation of pipelines from finished pipes without measuring the dimensions at the ship.

To eliminate the above problem, it is necessary to solve the following tasks:

- to analyze the standardized deviations controlled during the manufacture of pipes according to the drawings;
- determine the causes and magnitude of deviations of the structural dimensions that arise during the manufacture of pipes;
- compare the obtained deviation values with the standard;
- find tools to compensate or reduce the deviations that occur during the manufacture of pipes;
- to develop a pipeline routing technique that allows compensating for the influence of deviations that occur during the manufacture of pipes on the route displacement during installation of the pipeline;
- make appropriate changes to the standards relating to the design of pipelines.

The first four tasks require a scientific approach to their solution. They are indicated in [1, 5], where scientific approaches and justifications for their solutions are proposed, as well as the causes and magnitudes of deviations of the linear dimensions that arise when cutting and bending pipes are determined. In addition to these deviations, angular deviations of straight pipe sections occur. Installed welded joints also have angular deviations. Existing standards regulate angular deviations of the plane of the joint connecting surface relative to the axis of the pipe section. The angular deviations of the pipe sections to which the joints adjoin are not regulated by standards. This situation leads to the fact that the deviation of the connection is superimposed on the uncontrolled angular deviation of the pipe section.

The solution of the two remaining above problems is the goal of the research. Consider the effect of these deviations on the displacement of the pipeline route mounted from pipes made according to the drawings.

The existing regulatory documentation for the manufacture of pipes according to the sketches (in reserve) regulates the control of two parameters - this is the deviation of the construction dimensions of the pipe and the angle of non-perpendicularity of the installation of joints relative to the axes of the end sections.

|   | x  |   | X  |   | ΔX  | Δμ | Δx  |
|---|----|---|----|---|-----|----|-----|
| 3 | y  | 2080 | Y  | 456.5 | -1.0 | Δμ | -0.6 |
|   | z  | 450 | Z  | 2.5 | 6.5 | Δμ | 6.4 |
| 4 | x  | 1850 | X  | 1851 | 1.0 | Δμ | 0.8 |
|   | y  | 200 | Y  | 201 | 1.0 | Δμ | 0.8 |
|   | z  | 0 | Z  | 2.5 | 2.5 | Δμ | 2.3 |
| 5 | x  | 1940 | X  | 1941 | 1.0 | Δμ | 0.9 |
|   | y  | 200 | Y  | 201 | 1.0 | Δμ | 0.7 |
|   | z  | 0 | Z  | 3.0 | 3.0 | Δμ | 2.7 |
| 6 | x  | 1730 | X  | 1731 | 1.0 | Δμ | 0.4 |
|   | y  | 200 | Y  | 200.5 | 0.5 | Δμ | 0.5 |
|   | z  | 0 | Z  | 2.0 | 2.0 | Δμ | 2.2 |
| 7 | x  | 1850 | X  | 1851 | 1.0 | Δμ | 0.4 |
|   | y  | 260 | Y  | 261.5 | 1.5 | Δμ | 1.6 |
|   | z  | 0 | Z  | 1.5 | 1.5 | Δμ | 1.4 |
In the process of forming the configuration of the pipe on a pipe bending machine, several operations are performed - this is advancement to the beginning of the camber, the pipe was directly killed and the pipe was turned to perform the next camber in the desired plane. Errors of the last two operations lead to angular deviations of the directions of the straight sections of the pipe, including the end sections. The control of these deviations by existing standards is not regulated.

The installation of connections with control of perpendicularity relative to the axes of the end sections does not reduce angular deviations, but only adds new, chaotic directions.

Linear dimensions do not detect these angular deviations. The effect of these deviations is manifested during the installation of pipes, when the pipeline route deviates in unpredictable directions.

Tolerances for deviation of the structural dimensions of the pipes are regulated [1] and are ± 10 mm for pipes with a diameter of less than 100 mm and ± 15 mm for pipes of a larger diameter (table 2).

**Table 2. Permissible deviations of the coordinate pipe dimensions.**

| Form and diameter of pipes | Limit deviations, mm |
|----------------------------|----------------------|
| Straight pipe              | ±3                   |
| Bent pipes with a diameter up to 100 mm | ±10                  |
| Bent pipes with a diameter over 100 mm | ±15                  |

In addition to tolerances for the structural dimensions of the pipe, tolerances for the non-perpendicularity of the installation of joints are regulated (Table 3). They are regulated [1] and are presented in table. 2 depending on the diameter of the pipes (or 0.5° - European standard).

**Table 3. The deviation of the flanges (rings) from perpendicular to the axis of the pipe.**

| Conditional pass, mm | The deviation from perpendicularity (no more), mm |
|----------------------|-------------------------------------------------|
| Up to 100            | 2,0                                             |
| 100 to 200           | 4,0                                             |
| 200 to 400           | 6,0                                             |

Consider what can happen during the installation of a route consisting of only two pipes, if the pipes were manufactured in accordance with the requirements of the standards (Fig. 2).

The route consists of D65 pipes. The tolerance for the non-perpendicularity of the installation of the connection plane with the axis of the pipe is 2/100, where 2 mm corresponds to the tolerance for pipes with a diameter of less than 100 mm according to table. 17 [1], and 100 mm is the diameter of the connecting surface of the DN65 flange.

**Figure 2.** Scheme of deviations of the route after installing two pipes, which manufactured with permitted tolerances.
The linear tolerances on the structural dimensions for D65 pipes are $\pm 10$ mm [1].
As a result, the maximum permissible deviations of the route at the end of the first pipe along the Y axis will be: $10 + 2/100 \cdot 2000 = 50$ mm. This deviation is only the first pipe, however, the second connection on the first pipe can also be installed non-perpendicular within the tolerance, which will add a deviation to the second pipe, to its 50 mm, another $2/100 \cdot 2000 = 40$ mm. In addition, the permissible angular deviations of the straight sections of the pipe are: $\tan 0.3 \cdot 2700 = 14$ mm. Total deviation of the route will be: $10 + 2/100 \cdot 2000 + 2/100 \cdot 2000 + 10 + 2/100 \cdot 2000 + 14 = 154$ mm.
Pipes made according to drawings with such regulated tolerances cannot be mounted. The track does not fit in the corridor allocated for it in the project. The indicated deviations are detected only during the installation of the pipeline and lead to a displacement of the pipeline route from the corridor allocated for its laying. Pipes of large diameters made of non-ferrous metals, with compounds of the same metal, which have undergone the complicated technology of chemical treatment and coatings (including the application of an insulating layer), are of high cost. There is a situation when rather high costs for the manufacture of pipes are spent, but due to the impossibility of installing the pipes, they are rejected. This causes a refusal to manufacture pipes according to design drawings.

5. Conclusion

According to the results of the research it is proposed:
- change the system of assigning tolerances to the structural dimensions of pipes when issuing drawings, namely - indicate the only tolerance in one of the coordinate directions, in contrast to the current standards - indicate three tolerances in three coordinate directions;
- to develop a methodology for ensuring reliable piping tracing, based on the use of technological capabilities in the assembly of pipes with joints and taking into account the tolerances of the structural dimensions of pipes arising from their manufacture according to design drawings.

References
[1] Ngo G V 2018 Ph. D. thesis Astrakhan State Technical university 192
[2] Ersoy M 2016 *Asymptotic Analysis* 98(3) 237–55
[3] Endo M and Iwamoto J 1998 *Journal of Visualization* 1(3) 261–9
[4] Fan X N, Lin Y and Ji Z H 2007 *Shipbuilding of China* 48(1) 82–90
[5] Ngo G V 2017 *Bullentin of Admiral Makarov State University of maritime and inland shipping* 9(1) 157–64
[6] Sui H T and Niu W T 2016 *Frontiers of Mechanical Engineering* 11(3) 316–23
[7] Jiang W Y, Lin Y, Chen M anh Yu Y Y 2015 *Ocean Engineering* 102 63–70
[8] Zhang j Q and Liang Z S 2017 *International Journal of Applied Electromagnetics and Mechanics* 55(4) 507–22
[9] Ngo G V 2018 *Journal of Physics: Conference Series* 1015 032090
[10] Ngo G V 2018 *IOP Conference Series: Materials Science and Engineering* 537 032076
[11] Ngo G V and Tham B C 2019 *IOP Conference Series: Materials Science and Engineering* 537 032079
[12] Ngo G V 2019 *IOP Conference Series: Materials Science and Engineering* 537 032084