Experimental studies of the possible piping installation for ship systems

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Abstract. Improvement in the pipelines processability of ship systems at the stage of design and technical preparation with the possibility of making pipes without local dimensioning is considered in the current research work. In the course of the experimental calculation, the objective, the tasks and the plan of the experiment were developed; the necessary initial data were prepared. According to the experimental calculation result, the theoretical predictions were confirmed for the possibilities of assembling the pipeline routes at the design stage and the conceptual basis for eliminating total deviations by the routes transition. An algorithm has been developed for eliminating deviations of pipeline routes using mutually straight sections with pipe junctions and additional allowances. According to the research results, the prerequisites for the method development to improve the technological effectiveness of pipelines at the stage of design and technological preparation were created. With regard to a greater number of pipelines, it is possible to replace the inserting pipes with fitting pipes, which will be flexible according to the design dimensions without specifying the place, helping to reduce the time required for the construction of objects saturated with pipelines.

1. Introduction
The research results in [1-3] state as follows: by turning the straight pipes and using the loose couplings, it is possible to exclude actual deviations in the working process of the piping systems. However, these results are based only on the mathematical models, as well as simulations of the geometry. The research within the real experiment is needed to accept the results. Also to gain new knowledge to exclude deviations of ship pipelines routes in the conditions of installation connections in the mutual theoretical position and the permissible nonpendicularity with respect to the pipe axis [4, 5].

The experimental studies purpose is to verify the possibility of using straight pipes to ensure the pipeline routes assembling and to confirm the developed mathematics [1-3]. If for the majority of rigidly fixed junctions the area of actual deviations turned out to be less or equal to the attainability set, calculated for a specific pipe route, then the developed theoretical positions are consistent with practice (Figure 1a). And on the contrary, if the area of actual deviations is outside of (more than) the computational space of the attainability set (Figure 1b) it means that the proposed method is not possible, it is necessary to revise the theoretical foundations in combination with other methods of eliminating deviations [6-11].
Figure 1. Comparison of deviation domain (parallelepiped) with the attainability set (ellipsoid): a) full attainability set – attainability set assimilates the deviation domain; b) attainability set assimilation of the deviation domain

2. Materials and methods

Experimental studies were carried out at the leading shipbuilding enterprises of Vietnam. The main stages of experimental studies were carried out on the real pipelines of the ship systems of the Azimuth Rotor Tug 85-32W (project No. YN-512546) (Figure 2) in the process of their production at the shipyard LILAMA 69-2 and Damen Song Cam Shipyard in Vietnam.

The results of the experimental studies are the basis for the development of the methodological framework, its large-scale application in the production process of ship piping systems.

Figure 2. «Azimuth Rotor Tug 85-32W»

Main characteristics of the ship are noted in Table 1:

| Table 1. Main characteristics of «Azimuth Rotor Tug 85-32W» ship. |
|---------------------------------------------------------------|
| Length by CWL, m | 31.5 |
| Width, m | 13.7 |
| Board Height, m | 4.8 |
| Draft by CWL, m | 4.5 |
| Deadweight, t | 500 |
| Speed, knot | 12.5 |
Main engine power, kW

| 3 x Caterpillar 3512CTA (5400bW) |

Main stages of experimental research:

- choice of pipeline route between two rigid fixed junctions by the drawing and on board the ship;
- attainability set calculation and possible determination of pipeline route construction; function of fitting pipes with the technological allowance if necessary;
- drawing correction by measurement changes of fitting by allowance areas if necessary;
- production of the route according to the design information, including production of straight pipes with permissible displacement of flanges;
- measurements of actual deviations of assembled pipeline route;
- comparison of the actual deviations and computational attainability space;
- determination of the appropriate way of pipeline route replacement for actual deviation elimination;
- subsequent machining of the fitting pipe and the final installation.

3 Results and discussion

On the basis of the developed theoretical thesis [1] the calculation methods were worked out. As an example of calculation the pipeline route 23-2-321L00107 was considered, that is placed in the ship pipeline fuel system (Figure 3).

![Figure 3. Ship pipeline fuel system 321](image)

The analysis of pipeline route 23-2-321L00107 (Figure 4):
Coordinate dimensions of the calculated route consisting of four pipes are displayed in Table 2:

Table 2. Coordination points of the calculated route.

| Point number | X(FORE) | Y(PS) | Z(UP) |
|--------------|---------|-------|-------|
| 1            | 0       | 0     | 0     |
| 2            | -184    | 0     | 0     |
| 3            | -184    | 805   | 0     |
| 4            | -1397   | 805   | 0     |
| 5            | -4000   | 805   | 0     |
| 6            | -6753   | 805   | 0     |
| 7            | -6947   | 805   | 0     |
| 8            | -7240   | 805   | 125   |
| 9            | -7240   | 2000  | 125   |
| 10           | -7240   | 2000  | 105   |

Numbers of junction points: 1, 4, 5, 6, 10. Points 1 and 10 are placed on the end of the last pipe, so it is not involved in the installation and rotation of the pipes. Finally, the numbers of junction points are determined, where the free junctions are appointed: s = {4, 5, 6}.

The further analysis of the calculated route configuration is needed. The route 23-2-321L00107 consists of two straight pipes D_{65} (102-321L00107.02 and 102-321L00107.03) and two winded pipes D_{65} (102-321L00107.01 and 102-321L00107.04). It is detected that by the setting of two straight pipes 102-321L00107.02 and 102-321L00107.03 with the junction displacement the trajectory of the final point of the pipe always moves by the circular arch.

On the basis of the mathematical description [1, 3] the calculated parameters of the circle are to be determined, that are obtained by the pipe rotation with the assumed junction displacement (Table 3). The rotation of these areas under the definite turning angle makes up the arches that are necessary for the attainability set construction.

Table 3. Pipe vector parameters of the calculated route.

| №  | Pipe | Vector coordinates | Distance r, mm | D, mm |
|----|------|---------------------|----------------|-------|
| 1  | 1-4  | (-1397,805,0)       | 1612           | 70    |
| 2  | 4-5  | (-2603,0,0)         | 2603           | 70    |
| 3  | 5-6  | (-2753,0,0)         | 2753           | 70    |
| 4  | 6-10 | (487,1195,105)      | 1295           | 70    |

The developed formula in [1, 3] determines the trajectory of the last A route point displacement. This trajectory states as follows:
\[
\begin{align*}
X &= r_1 \cos \theta_1 + r_2 \cos \theta_2 - X_4 + X_6 \\
Y &= r_1 \sin \theta_1 \cos \varphi_1 + r_2 \sin \theta_2 \cos \varphi_2 - Y_4 + Y_6 \\
Z &= r_1 \sin \theta_1 \sin \varphi_1 + r_2 \sin \theta_2 \sin \varphi_2 - Z_4 + Z_6
\end{align*}
\]

Or:

\[
\begin{align*}
X &= 2603 \cdot \cos \theta_1 + 2603 \cdot \cos \theta_2 - (-1397) + (-6603) \\
Y &= 2603 \cdot \sin \theta_1 \cdot \cos \varphi_1 + 2603 \cdot \sin \theta_2 \cdot \cos \varphi_2 - 805 + 805 \\
Z &= 2603 \cdot \sin \theta_1 \cdot \sin \varphi_1 + 2603 \cdot \sin \theta_2 \cdot \sin \varphi_2 - 0 + 0
\end{align*}
\]

with \( \theta_1, \theta_2 \) – cross angle \([0, \alpha]\); \( \varphi_1, \varphi_2 \) – turning angle \([0, 2\pi]\).

As the result of the calculation the coordinates of attainability set are determined (mm):

\[
\begin{align*}
X &\in (-0.01; 0) \text{ mm} \\
Y &\in (0; 124) \text{ mm} \\
Z &\in (0; 124) \text{ mm}
\end{align*}
\]

If the theoretical thesis of rigidly fixed junctions of the route are considered as a central point of coordinate system the following mark can be used: \( X = 0 \text{ mm}; Y = \pm 62 \text{ mm}; Z = \pm 62 \text{ mm} \).

The border of the reachability area is the largest value by which the piping workers can move the point 10 to eliminating the route deviation. It is necessary to provide the axes direction of the final pipe area 6-10 to be coincided with the direction to the rigidly fixed subspace (equipment, fitting…) which is perpendicular to the axes.

Two straight pipes are to be chosen (102-321L00107.02 and 102-321L00107.03) as special pipes. This data must be noted in the drawing for workers to produce the straight pipes 102-321L00107.02 and 102-321L00107.03 with the assumed junction deviation in workshop and to use free junctions in point 4 and 5 of the route. As magnitude \( OX \) in the direction of the attainability set is equal to zero, it is necessary to state the allowance size as 100 mm in this direction. The pipe 102-321L00107.04 is chosen for the route 23-2-321L00107 as the fitting pipe with the stated allowance 100 mm size by the direction \( OX \) in the area 6-7. The rest pipes can be produced as semi-production. The definite attainability set is displayed by the trajectory of the last point of the pipeline route (Figure 5).

**Figure 5.** The attainability area of route.

Author offers the production of the straight pipes 102-321L00107.02 and 102-321L00107.03 with the assembled junction displacement on the platen: to measure the pipe length, to set the junctions, to remove junction axes by the platen with the permissible value calculated from the pipe length and fix the pipe, keeping it in the measuring position.

After that the workers shall bring all the pipes (main and fitting pipes) simultaneously to the vessel for installation. During the experiment the piping workers will measure the actual deviations in the pipeline installation in situ (Figure 6). These are precisely the quantities that must be excluded to connect the route to other routes or other equipment. In order to know whether the proposed method can be applied to exclude these deviations, the workers need to compare the point of the area of actual deviations with the calculated attainability set points.
Especially in this case the workers measure the actual deviation: \( \Delta X = 48 \text{ mm} \), \( \Delta Y = 49 \text{ mm} \), \( \Delta Z = 31 \text{ mm} \). Then they compare the points of the attainability set and see that the magnitudes of deviations in the direction of OY and OZ are less than the points of attainability set. By turning the straight pipes 102-321L00107.02 and 102-321L00107.03, produced with the admitted displacement in the free junction the piping workers can remove the final route point to the place of adjustment with the rigidly fixed junctions in the OY and OZ directions. To eliminate deviations in the OX direction, the workers cut off the excess allowance: \( 100 - 48 = 52 \text{ mm} \) in the fitting pipe 102-321L00107.04. Thus, the successful installation is seen without waiting for the measurements for the production of inserting pipes as by the traditional method. As a result, the delivery time of shipbuilding orders will be reduced.

![Figure 6. Taking measurements of the actual deviations in situ](image)

Thus, by the proposed method we can completely eliminate the actual deviations. A pair of straight pipes Dy65: 102-321L00107.02 and 102-321L00107.03. Permissible displacement with the length of the specified pipes 2063: 62 mm. The pipes are made with a flange offset of 60 mm within allowance, that is, a shift of 120 mm (more than 10 mm) is carried out. In the pipeline installation process, all deviations of the welded glasses displacement are excluded.

At the stage of design and technological preparation, the analysis and determination of allowance points were carried out, pipeline drawings were corrected with indication of the points and directions of these allowances, as well as pipe sections where the allowances should be assigned. Thus, pipes can be produced according to the drawings, it is not required to take measures in situ. For the rest of the routes the appropriate calculations were carried out. According to the proposed method, 75 lines from finished pipes and fitted pipes were successfully installed according to design information without using an inserting pipe of 88 considered routes (85%). For the 13 remaining routes, it is required either to assign an inserting pipe, or use parallel pipe sections or correct their configuration.

| Route name         | Theoretical | Actual deviations, mm | Quantity of straight pipes | Attainability set, ± mm | Allowance, mm |
|--------------------|-------------|------------------------|----------------------------|-------------------------|---------------|
|                    | coordinates of the route end, mm |                        |                            |                          |               |
| 1-1-351L00120      | X           | 129                    | 11                         | 3                       | 78            |
|                    | Y           | 320                    | -25                        |                         | 67            |
|                    | Z           | 868                    | 32                         |                         | 78            |
| 3-1-351L00130      | X           | -310                   | -20                        | 2                       | 93            |
|                    | Y           | 888                    | 17                         |                         | 93            |
|                    | Z           | -4571                  | -32                        |                         | 100           |
By the theoretical calculations results of piping routes, 88 routes can be classified into 4 groups in accordance with their installation opportunities (Figure 7):

1) 19 routes (22% of the whole quantity of the analyzed pipeline routes) have got the opportunity of full deviation eliminating in three directions – the first level of possibility of piping installation (group I). All pipes of these routes can be produced according to the project data and do not require the allowance. Thus the pipeline route correction is not required in this case. But it must be noted in the drawing for the workers in the workshop to know that all pipeline routes are “finished”.

2) 39 routes (44% of the whole quantity of the analyzed pipeline routes) have got the opportunity of the deviation eliminating in two directions (group II) and it is necessary to clarify the allowance in the third direction for full deviation eliminating – the second level of possibility of piping installation. All pipes of these routes can be produced according to the project data and do not require the allowance. Thus the pipeline route correction is not required in this case but it is needed to clarify the allowance on the pipe that corresponds to the necessary direction within the calculation. It must be noted in the drawing for the workers in the workshop to know that all pipeline routes are “fitted”.

3) 17 routes (19% of the whole quantity of the analyzed pipeline routes) have got the opportunity of the deviation eliminating in one direction (group III); and it is necessary to clarify the allowance in the rest two directions for full deviation eliminating – the third level of possibility of piping installation.

4) 13 routes (15% of the whole quantity of the analyzed pipeline routes) do not have any opportunity of deviation eliminating – the fourth level of possibility of piping installation (group IV). In this case the pipeline routing correction is required.

The results of the experimental studies are the basis for the development of the methodological framework, its large-scale application in the production process of ship piping systems.

4 Conclusion
As a result of experimental studies of the possible assembling of straight pipes, the following was established:
  * Confirmed theoretical predictions of the possible assembling of the pipeline routes at the stage of design and technological preparation;
A procedure for eliminating deviations of pipeline routes using straight sections with pipe junctions and additional allowances has been developed;

Prerequisites have been created for the development of appropriate methods for improving the technological effectiveness of pipelines at the design stage.

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