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Analytical determination and dimensional control of the stand curves required for the assembly of complex-shaped naval block sections

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Abstract. The usual devices for assembling curved naval block sections shall be designed having regard to the regulatory distance of the ship. Even if universal devices are used, they shall be adapted for each cross-section of the ship. In this respect, it is important that the curved surface of the hull is expressed through numerical methods so that the most accurate analytical description of the stand curves required for the construction of the assembly device can be obtained. This work sets out how to calculate and verify the stand data required for the assembly of complex-shaped naval block sections in relation to the outer cover of the vessel

1. Introduction

The universal assembly device with point support uses support rods (pins) to generate the negative output of the outer surface of the hull, distributed in the meshes of a fixed pitch orthogonal network (Figure 1).

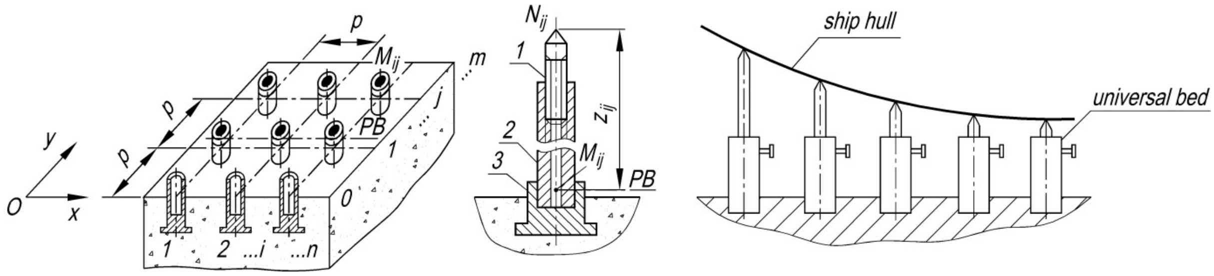

Figure 1. Universal assembly device with point support: *1* – support screw cone; *2* – standard tubular section; *3* – tubular fixing body

The support rods have vertical axes and adjustable height, being fixed by various methods to the floor of the assembly workshop. By adjusting the height of the tips of the threaded supporting cones, the negative of the naval block section can be generated in relation to the baseline plan inclined at an angle to the projection plans. The position of the base plan shall be such that the heights of the four corners of the naval block section are approximately equal and the minimum height of the supporting threaded cones in the central area allows access for specific welding operations.

Tube fixing bodies are embedded in the floor of the assembly workshop, on which the base plan of the universal assembly tool materializes. The *p*-step of the tubular fixing bodies is usually constant in the directions *O'x'* and *O'y'* and has values between (500...1000) mm.

The cylindrical rods of standard tubular sections *2* are inserted in the tubular fixing bodies *3*, provided at the top with a supporting threaded cone *1*. By introducing an appropriate number of tubular sections and adjusting the length of the support screw cone, the required height is obtained for the support tips, which generate the negative of the naval block section. The tubular sections can be assembled by threading or by locking with screws.

2. Determination of the stand curves

The determination of the stand curves for a naval block section shall initially be done without taking into account the thickness of the outer cover. In a first approximation it is necessary to find translation relationships from the general coordinate system, relative to the vessel, to the local coordinate system, in relation to the base plan of the assembly stand. This means that by moving one of the axle systems according to any law, we can overlap it over the second axis system with minimum error of approximation (Figure 2). The determination of *the* z_{ij} *heights* of the pins in the mesh of the network given by M_{ij} (x_i, y_j), is based on calculation programs which must solve the following problems.

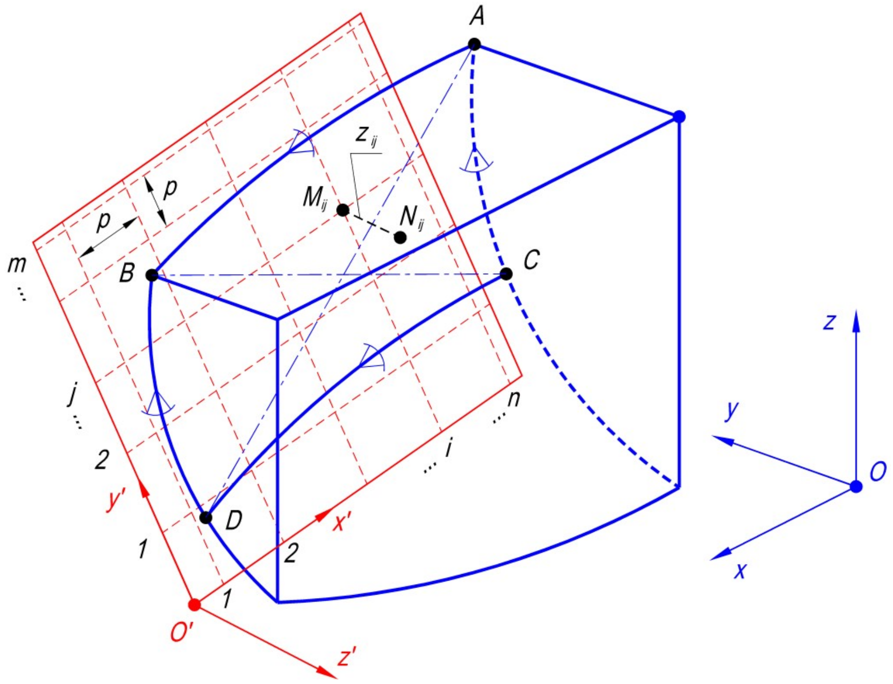

Figure 2. Correlation of fixed and relative axis systems s

2.1. Definition of the baseline plan

The *O'x'y* base plan is referred to the *Oxyz* vessel's general coordinate system, originating in the master torque and the coordinate axes given by the intersection lines of the main projection plans (Figure 2). Thus, the base plan has, in the vessel's general coordinate system, the general equation

$$A \cdot x + B \cdot y + C \cdot z = 0 \qquad (1)$$

Figure 2 represents an axonometric section of boarding section delimited by four mounting welds, two longitudinal welds *(AB* and *CD)* and two transverse welds *(AC* and *BD).*

If the *ABCD* surface is analytically expressed, the problem is reduced to the calculation of the distance between the meshes M_{ij} of the network of the universal stand and the N_{ij} points given by the intersection of the normals to the basic plan (taken through the meshes of the network) with the cover of the block section. In the base plan, the M_{ij} points have the coordinates

$$\begin{cases} x_i^{'} = i \cdot p; \\ y_j^{'} = j \cdot p. \end{cases} \quad (2)$$

The base plan is usually parallel to a plan tangent to the surface of the naval block section and equally spaced from its corners. To define this plan, the equation of one of the diagonals of the ship's block section (for example, line *BC*) shall be written. The equation of the plan containing the *BC* line is then determined and is equal to the *A* and *D* points. Finally, the baseline equation will be determined as an equation of the plan parallel to the tangent plan to the naval block section, located at a distance equal to the minimum space required to provide access for humans under the metal structure [1].

2.2. Orientation of the base plan

In principle, the *O'x'* and *O'y'* axes may be oriented in any case in the base plan. In the orientation of the axes it is intended that the norms applied to the base plan (through the mesh of the network) will cover the entire block section surface. It is therefore preferable to define the O'x' axis as the intersection of the base plan with the plan containing the *CD* rope and is normal to the base plan. The *O'y axis* will be defined as the intersection of the base plan with the normal plan at *the O'x'* axis and passing through *B* or *D* points.

2.3. Determination of the height of support points

The problem can be solved by defining the base plan normal equations at the M_{ij} points and resolving the equation system consisting of the *ABCD* surface equation and the normal equations to it. This gives the coordinates of the N_{ij} support points and z_{ij} can be calculated with the classic relationships in the analytical geometry.

It should be noted that the height of the support points can also be determined by conventional path methods (in the absence of analytical representation of the naval block section surface), but the workload is greatly increased.

2.4. Determination of the mounting angles of the frame elements

The mounting angles of the frame elements shall be calculated as angles made in space between the *O'z'* axis (normal to the base plan) and the *Oy* and *Ox* axes respectively (transverse and longitudinal axis of the *Oxyz* vessel's general coordinate system). In the case of reinforcement block sections, the cores and the reinforcement stringers shall be assembled at these angles relative to the vertical of the place using special lead wire rapporteurs or other equivalent devices.

3. Determination of the mathematical calculation support

In order to obtain the necessary data for the construction of the universal stand for the assembly of the naval sections in normal position, it is necessary to find the translation formulas from the fixed coordinate system in relation to the ship to the relative coordinate system in relation to the base plan of the naval block sections. In other words, the aim is to move from the *Oxyz* axis system with the versors *i*, *j*, *k*, to the *O'x'y'z'* axis system with the versors *i'*, *j'*, *k'*.

The origin of the relative *O'x'y'z'* axis system in relation to the *Oxyz* fixed axis system is considered to have the coordinates *O'* (x_0, y_0, z_0) and the versors, of components *i'* (a_1, b_1, c_1), *j'* (a_2, b_2, c_2), *k'* (a_3, b_3, c_3), relative to the fixed axis system.

The components of the versors of the relative axis system shall meet the equations [2]

$$\begin{cases} a_1^2 + b_1^2 + c_1^2 = 1, \\ a_2^2 + b_2^2 + c_2^2 = 1, \\ a_3^2 + b_3^2 + c_3^2 = 1, \end{cases} \text{ respectively } \begin{cases} a_1 a_2 + b_1 b_2 + c_1 c_2 = 0, \\ a_2 a_3 + b_2 b_3 + c_2 c_3 = 0, \\ a_3 a_1 + b_3 b_1 + c_3 c_1 = 0. \end{cases} \quad (3)$$

In other words, the matrix

$$A = \begin{vmatrix} a_1 & b_1 & c_1 \\ a_2 & b_2 & c_2 \\ a_3 & b_3 & c_3 \end{vmatrix} \tag{4}$$

is orthogonal.

In order to establish the transformation relations, a point *P* in space shall be considered having the coordinates *x, y, z* with respect to the fixed axis system and the coordinates *x', y', z'* with respect to the relative axis system. In these circumstances, it can be written

$$\begin{cases} OP = x \cdot \bar{i} + y \cdot \bar{j} + z \cdot \bar{k}; \\ OO' = x_0 \cdot \bar{i} + y_0 \cdot \bar{j} + z_0 \cdot \bar{k}; \\ O'P = x' \cdot \bar{i}' + y' \cdot \bar{j}' + z' \cdot \bar{k}'. \end{cases} \tag{5}$$

By expressing the vectors of the relative axis system based on matrix *A* and considering that the vectors of the fixed axis system are not coplanar, the overall relationship of transition from one reference system to another is obtained, i.e.

$$\begin{cases} x = x_0 + a_1 x' + a_2 y' + a_3 z'; \\ y = y_0 + b_1 x' + b_2 y' + b_3 z'; \\ z = z_0 + c_1 x' + c_2 y' + c_3 z'. \end{cases} \tag{6}$$

A system of equations (6), processed with a specialized software [3], can be set up in a test mode for stand curves with an approximation error of 10^{-11} order.

4. Correction of the equations of the stand curves

In order to correct the stand data, depending on the thickness of the metal sheets of the naval block section, in the second approximation, account is taken of the thickness of the metal sheets of the cover and the angle that the tangent makes to the surface of the block section cover at the point of calculation with the horizontal line.

The point *P (x, y, z)* is considered as belonging to the theoretical line of the naval block section cover and the metal sheet thickness of the cover equal to the unit (Figure 3). A vertical line is lowered from point *P* until it intersects the opposite face of the metal sheet in point *P' (x', y', z')*.

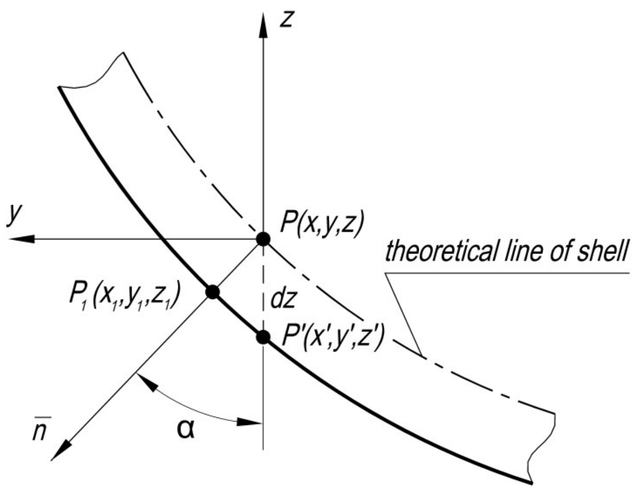

Figure 3. Correction of the equations of the stand curves

It is assumed that only the z coordinate is changed and the x and y coordinates are constant. The normal to the cover at point P intersects the opposite side at point $P1$ $(x1, y1, z1)$. Considering that the opposite sides of the metal sheet are parallel, the PP_1P' triangle will be rectangular at point P_1. Therefore, the calculation relationship is established

$$\mathrm{d}z = \frac{1}{\cos\alpha} \tag{7}$$

For various thicknesses of metal sheet and different angles of inclination of the cover relative to the horizontal line, complete Table 1.

Table 1. Summary for stand data corrections by *Oz'* axis [4]

t \ α	0^0	1^0	2^0	3^0	…	90^0
1	$\mathrm{d}z_{11}$	$\mathrm{d}z_{12}$	$\mathrm{d}z_{13}$	$\mathrm{d}z_{14}$	…	$\mathrm{d}z_{1n}$
2	$\mathrm{d}z_{21}$	$\mathrm{d}z_{22}$	$\mathrm{d}z_{23}$	$\mathrm{d}z_{24}$	…	$\mathrm{d}z_{2n}$
…	…	…	…	…	…	…
In the case of intermediate inclinations, an approximation shall be made by interpolation						

Therefore, the corrected coordinate of the P point, according to the *Oz'* axis, will have the expression

$$z' = z - \mathrm{d}z = z_0 + c_1 \cdot x' + c_2 \cdot y' + c_3 \cdot z' - \frac{1}{\cos\alpha} \tag{8}$$

Similarly, corrections according to *the Oy'* and *Ox'* axes shall be made. Thus, the following calculation relationships are obtained

$$\mathrm{d}y = \frac{1}{\sin\alpha}; \quad \mathrm{d}x = \frac{1}{\tan\alpha}. \tag{9}$$

The corrected coordinates of the P point, accoring to the *Oy'* and *Ox'* axes, will have the expressions

$$\begin{cases} y' = y - \mathrm{d}y = y_0 + b_1 \cdot x' + b_2 \cdot y' + b_3 \cdot z' - \dfrac{1}{\sin\alpha}; \\ x' = x - \mathrm{d}x = x_0 + a_1 \cdot x' + a_2 \cdot y' + a_3 \cdot z' - \dfrac{1}{\tan\alpha}. \end{cases} \tag{10}$$

5. Dimensional control of the stand curves

For the purpose of dimensional control of the stand curves proceed as follows:

- after welding the frame, the attachments shall be removed and the work for technical handover completed;
- The 3D coordinates obtained with the measuring devices are transferred into a specialized software [3], which converts them into local coordinates, and then remeasure the points with a theodolite;
- a measurement sheet with dimensional deviations from the technical design shall be drawn up;
- the deviations shall be corrected and the dimensional check shall be re-made.

The problem of centering the metal sheets of the stand block section can be resolved by marking the position of at least two support points on each metal sheet of the cover, to be brought into the corresponding supporting peaks.

The marking on the block section cover of the positions of the control water lines is made based on the coordinates of the l_{ij} curviliniar of the points of water lines, in relation to one of the assembly welds of the naval block section. These coordinates shall be determined from the vessel's shape plan (Figure 4), marked on the cover of the block section at the theoretical lines of the sides, considering as origin the appropriate longitudinal mounting weld (C_s upper seam or C_i lower seam). By joining the marked points on the cover of the naval block section, the desired waterline is obtained.

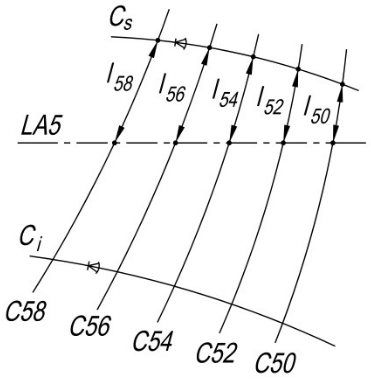

Figure 4. Drawing control water lines on the cover of the naval block section

A drawback of the point-supported universal stands is that the top of the support rods is damaged by spot welding the block sections cover, which requires regular rectification and replacement.

6. Conclusions

Universal point-supported stands are an economic solution, but the traditional methodology of building them provides relatively low accuracy. This is because it is not possible to precisely materialize the position of the weld beads, making it difficult to center and position them. It shall also not be possible to accurately trace on the cover of the block section the positions of the water lines required for centering operations for the assembly of the hull of the vessel.

In order to eliminate miscentering and positioning of naval block sections on universal stands, analytical translation relationships have been established from the general coordinate system in relation to the vessel to the local coordinate system in relation to the base plan of the stand. The stand data necessary to accurately materialize the negative hull of the vessel were obtained by analytical means, taking into account the thickness pf the cover of the naval block section.

Using a specialized software, the approximation errors are substantially reduced by 10^{-11} order, so the analytical method of checking the stand curves becomes much more versatile than the conventional method.

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