Study of Shape Forming of Welding Bevel in Openings of Pressure Hulls of Underwater Shipbuilding Objects

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Abstract. The problem of ensuring bevel accuracy for elements of saturation welding with hulls of the ships and vessels in the conditions of slipway production is relevant for modern shipping. The shape forming of hole bevel surface is often complicated by the spatial position of the holes relative to the basic coordinate planes. Therefore, such holes are currently marked and opened manually in a pressure housing. This negatively impacts both the quality and the performance of hole processing. The problem of ensuring high accuracy of the shape and location of the welding bevel in the large thickness high-strength steel housing with sufficient processing performance can be solved by CNC machining. However, the use of stationary metal-cutting equipment for the preparation of the welding bevel after the completion of the General Assembly of the ship's hull is not rational due to its large dimensions. The use of traditional mobile machines for these purposes, in turn, is inefficient due to the low rigidity and vibration resistance of their design. The article proposes a solution that includes the use of mobile equipment with parallel kinematics and software control, equipped with a cutting tool of a special design. To do this, a brief analysis of the shape of the welding bevel surface for a spatially located hole is made. Options of bevel processing with advantages of the modern cutting tool and the mobile equipment are considered. The function of shape forming is presented in the form of unified matrix parametric equations for various processing schemes and applied tools.

Keywords: Underwater shipbuilding objects · Saturation elements · Shape forming of welding bevel · Mobile equipment · Milling · Function of shape forming

1 Introduction

The structure of pressure hull of most objects of underwater shipbuilding objects includes holes of different shape, size, and spatial location relative to basic ship coordinate planes. The holes are generally provided for the welding of saturation elements, such as welds, branch pipes, and taps. A large number of holes are opened on the building berth when the

A. A. Radionov and V. R. Gasiyarov (eds.), *Proceedings of the 6th International Conference on Industrial Engineering (ICIE 2020)*, Lecture Notes in Mechanical Engineering, https://doi.org/10.1007/978-3-030-54814-8_19

assembly of the hull has already been completed. Therefore, the problem of improving the quality of welding of saturation elements into a pressure hull of underwater shipbuilding objects is urgent.

Practice shows that among all preparatory operations the highest impact on the quality of installation of the welded elements is the accuracy of the welding bevel in the respective holes.

Technologically, the step of processing the welding bevel in the above-mentioned holes is complicated by the following circumstances:

- Limit of possibility to use stationary metal-cutting equipment due to considerable size and rather complicated shape of hull and difficult access of working zone of treatment;
- Various versions of hole axes arrangement relative to general ship coordinate planes;
- Complexity shape of welding bevel in openings of hulls with relatively large thickness;
- High forces and heat generation due to processing of high-strength hard-to-process shipbuilding materials, which are widely used for manufacturing of pressure hulls.

In general, the welding bevel surface is a surface of double curvature. Generally, the welding bevel surface of the hole (Fig. 1) is a linear surface with three guides, that is, a double-oblique cylinder [1]. In either case, the chamfer surface generatrix is a line of constant profile shape. The welding bevel surface is shape formed by moving the generatrix along three guides, one of which is straight and coincides with the axis of the produced hole, and two curved guides are located on the edges of the hole in the hull (see Fig. 1).

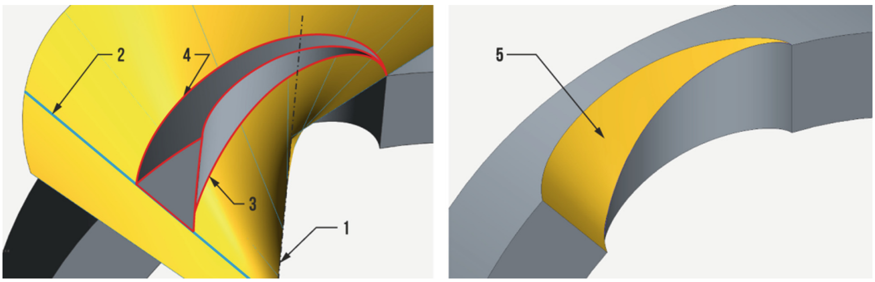

Fig. 1 Applying a surface to shape-forming a bevel's surface: 1—rectilineal guide; 2—rectilinear generatrix; 3—first curvilinear generatrix (start of bevel); 4—second curvilinear generatrix; 5—bevel edge cut off with a ruled surface double-oblique cylinder

2 Methods and Materials

The technology of processing the hole for welding of the saturation element into the hull on the staple implies preliminary opening of the hole in the hull with an allowance. Next, the weld bevel is processed along the contour of the open hole. At present, this operation is carried out manually, which does not provide the required processing accuracy and is quite time consuming. The bevel geometry determination is made by using the descriptive geometry methods.

Improvement of accuracy and efficiency of the considered treatment is possible when using non-stationary processing complexes (NPC) with numerical program control [2], including industrial robots (manipulators).

Installation of such equipment can generally be carried out at a technologically conditioned location with respect to the axis of the hole to be treated, including coaxially.

In either case, the position of the tool during machining is programmatically determined by its path, which is directly dependent on the shape of the surface and tool being machined.

If bevel angle is variable along the perimeter of the hole, the tool position is set by five simultaneously controlled coordinates.

If the bevel angle is constant, only three control coordinates are sufficient to uniquely describe the tool path. However, with the combination of large hole sizes and their defined positions relative to the ship's coordinate system, a gouging will be observed. The amount of gouging must be controlled taking into account the regulatory requirements for the accuracy of the geometry of the bevel being performed.

Consider the traditional type of carving used in shipbuilding—angular with a rectilineal generatrix of bevel.

There are several options for machining a surface of a specified shape. The most practical of these are the following (see Fig. 2) [3, 4].

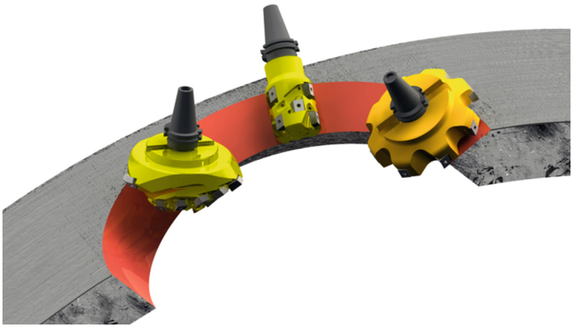

Fig. 2 Bevel shape-forming schemes with corner, cylindrical, and end mills

- Processing by a cylindrical mill. Forming of surface is performed by touching method. When machining bevel with blades of cylindrical cutter, constant angle of inclination of machined surface is provided by angle of inclination of mill rotation axis relative to hole axis. In the case of a variable angle, the orientation angle of the mill will change by an additional two coordinates. It is characteristic of the process of this method that the thickness and width of the shear layer have a variable value. Maximum and equal thickness will be achieved by the counter milling scheme when the tool leaves the cutting zone. The cutting width will be the maximum when cutting the cutter, and the minimum when the cutter leaves the cutting zone.

- Processing by a conic mill. The forming of the surface in this case is also performed by the touch method.
- Processing by a face mill.

When designing non-stationary processing complexes (NPC), the main criteria are the criteria of shape-forming quality, and cutting quality (optimality of direction and value of forces arising during processing). All components of NPC are designed on the basis of these criteria, as they determine the static and kinematic accuracy of shape forming.

The rigidity and accuracy of the processing system will depend on the selected schematic diagram of the NPC and on milled materials [5].

In the context of the article, an example of a machine with parallel kinematics on a rotating base is chosen [6–10], see Fig. 3.

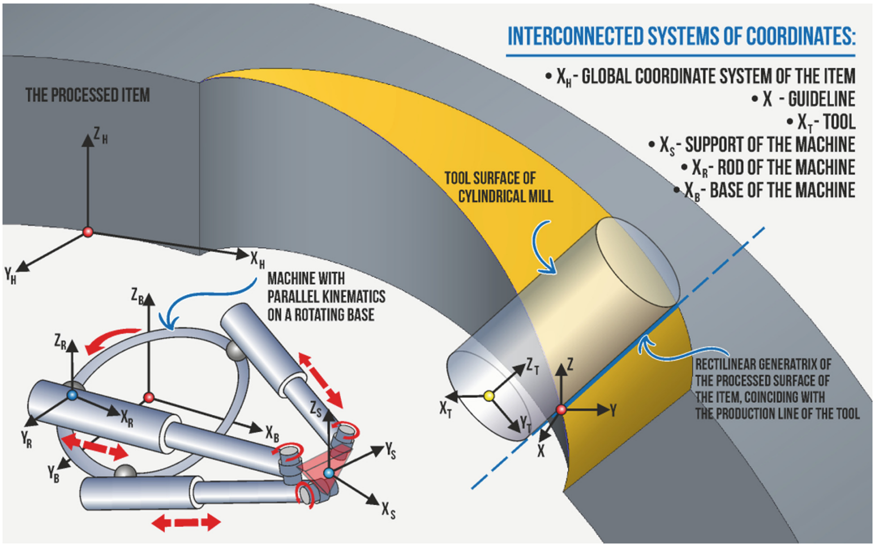

Fig. 3 Components of process complex with coordinate reference

3 Results

Requirements for accuracy of shape and dimensions of processed welding bevel can be achieved on the basis of application of a single mathematical model [11], potentially used for model studies of processing results, direct programming of processing with CNC, preparation of design [12], and technological documentation [13, 14].

Such a mathematical model has been developed on a single methodological basis. It combines sequentially the surface to be treated and all components of NPC [15–18], see Fig. 3:

- Tool (it directly performing the function of shape forming the treated surface);
- Machine support (it directly performing kinematic function of movement of the power unit along the specified path);
- Machine rod (it directly performing the function of transfer of control movements from the base to the support and reverse transfer of forces and moments to the base);
- Machine base (it directly performing the function of reproducing the profile of the working tool path guide);
- The processed item (in the context of the article—the hull, which directly performs the function of a global base for binding of local coordinate systems of components of NPC).

The basis of the model creation is typical forms of description of components of NPC in homogeneous coordinates [19–21]. It combined in a matrix equation or inequality according to the structure of NPC.

The overall structure of such a model can be represented as:

$$\left[V_{i-n}\right]\cdot\left[V_{i-n-1}\right]\cdot\ldots\cdot\left[V_{i-2}\right]\cdot\left[V_{i-1}\right]=[V_i] \tag{1}$$

where n is the total number of interconnected components of the NPC, including the product; $\left[V_{i-m}\right]\big|_{m=0,\ldots,n}$—the radius vector of characteristic points of the NPC component in the system of coordinates of the NPC component of (i–m)-level. It parametrized (according to the normative document) by the main parameter of shaping ξ, i.e., relative angle of rotation of bevel section. The vector of each subsequent level, for example, $[V_i]$ is obtained as a product of standard linear-angular transformations matrix $\left[A_{i-m}\right]$ and a radius vector of previous level $\left[V_{i-m}\right]$:

$$\left[V_{i-1}\right]=\left[A_{i-1}\right]\cdot\begin{bmatrix}x_{i-1}(\xi)\\ y_{i-1}(\xi)\\ z_{i-1}(\xi)\\ 1\end{bmatrix}=\begin{bmatrix}x_i(\xi)\\ y_i(\xi)\\ z_i(\xi)\\ 1\end{bmatrix}=[V_i] \tag{2}$$

For the NPC, as shown in Fig. 3, the model can be presented as:

$$[A_H]\cdot[A_B]\cdot\{[A_R]\}\cdot[A_S]\cdot[A_T]\cdot\begin{bmatrix}x_T(\xi)\\ y_T(\xi)\\ z_T(\xi)\\ 1\end{bmatrix}=\begin{bmatrix}x(\xi)\\ y(\xi)\\ z(\xi)\\ 1\end{bmatrix} \tag{3}$$

$[A_T]$—a transformation matrix of characteristic points from the coordinate system of the producing tool surface to the coordinate system of the work surface;

$[A_S]$—a transformation matrix of characteristic points from the coordinate system of the support of the machine to the coordinate system of the tool;

$\{[A_R]\}=\left\{\begin{matrix}[A_{R1}]\\ [A_{R2}]\\ [A_{R3}]\end{matrix}\right\}$—a matrix of parallel-connected transformations of characteristic points from the coordinate system of the machine rod to the coordinate system of the machine support;

$[A_B]$—a transformation matrix of characteristic points from the coordinate system of the base of the machine to the coordinate system of the machine rods;

$[A_H]$—a transformation matrix of characteristic points from the item coordinate system to the machine base coordinate system.

4 Discussion

Using the presented generalized model, static problems (determination of coordinates, paths, static errors) are solved in their own coordinates, and kinematics and dynamics problems (determination of fields of instantaneous speeds and accelerations, forces and moments, deformations) are solved in non-basic ones.

The generalized matrix equation (inequality) of the presented mathematical model can be solved with respect to any of the components of the NPC. In particular, in order to design a special tool directly implementing the shape-forming function, it is sufficient to express in the above equation the radius vectors of points of the tool surface through the inverse transformation matrix and the radius vectors of the corresponding points of the treated surface.

In general, when considering the coordinate systems (S) of the machined surface and the points of the cutting blade of the tool (S_T), the position of the latter in the coordinate system of the machined surface in a particular section will be determined by the radius vector:

$$[V_T] = [A_T]^{-1} \cdot [V] \tag{4}$$

where $[V]$ and $[V_T]$—accordingly, the radius vectors of the points of the treated surface and the cutting blade of the tool, respectively, in their own coordinate systems; $[A_T]^{-1}$—inverse coordinate transformation matrix.

5 Summary

Technological conditions of welding bevel of holes in pressure hull of submarines are analyzed.

A brief description of the features of the bevel form shaping is given.

A review of possible options for replacing manual treatment of holes for housing saturation elements with non-stationary processing complexes with the possibility of using metal-cutting tools is given. They might significantly improve accuracy of hole edge processing.

A model of bevel form shaping of treated holes with the help of matrix dependencies in uniform coordinates in the system of coordinates of the treated surface is proposed.

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