Optimizing the Layout of Rectangular Hull Tiles

Nian-qing Wu[*], Yao Zhao and Hua Yuan

School of Naval Architecture & Ocean Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

Abstract: Rectangular tiles can be laid on a ship's hull for protection, but the sides of the tiles must be adjusted so adjacent tiles will conform to the curvature of the hull. A method for laying tiles along a reference line was proposed, and an allowable range of displacement for the four vertices of the tile was determined. Deformations of each tile on a specific reference line were then obtained. It was found that the least deformation was required when the tiles were laid parallel to a line with the least curvature. After calculating the mean curvature on the surface, the surface was divided into three layout areas. A set of discrete points following the least deformation of the principal curvatures was obtained. A NURBS interpolation curve was then plotted as the reference line for laying tiles. The optimum size of the tiles was obtained, given the allowable maximum deformation condition. This minimized the number of bolts and the amount of stuffing. A typical aft hull section was selected and divided into three layout areas based on the distribution of curvature. The optimum sizes of rectangular tiles were obtained for every layout area and they were then laid on the surface. In this way the layout of the rectangular tiles could be plotted.

Keywords: layout design; laying rectangular tiles; reference line; principal curvatures; size optimization

Article ID: 1671-9433(2010)03-0307-05

1 Introduction

The rectangular tiles (Chen *et al*., 2006; Chen *et al*., 2007a) are flexible and applied to the outer hull of ships under the action of process tooling. They are used for ship protection. Now it is able to lay them based on the computerized three-dimensional surface model. The optimum (Guo *et al*., 2003; Yu *et al*., 2003; Wu *et al*., 2007; Kaveh and Shahrouzi, 2006; Pugsley *et al*., 2006) layout design of the rectangular tiles is necessary because it influences the layout quality denoted by the deformation of them and the layout workload denoted by the number of fixing bolts and the amount of stuffing. Therefore, they could impact the ship construction period and costs.

The method of laying rectangular tiles along the reference line is presented based on the generation algorithm of rectangular tile on ship hull proposed by Chen *et al*. (2007b). The deformations of one rectangular tile laid along different reference lines with its centroid at any point on a complex surface of ship hull were then obtained and it could be found that the minimum deformations of the rectangular tile occur when it is laid along the principal direction corresponding to the smaller value of the principal curvatures. The maximum and minimum values of the curvatures on the surface are obtained and the color filled contour maps of them are plotted. Then the surface is divided into three layout areas and for every layout areas, the optimum size of the rectangular tile is obtained subjected to allowable maximum deformation

condition. Typically, the surface of aft hull section is selected and divided into three layout areas. For each area, the optimum dimension of the rectangular is then obtained. The rectangular tiles are laid respectively on every layout area of the surface. Consequently, the layout design drawing is obtained.

2 Optimum direction of laying rectangular tiles

Generally, the reference lines along which the rectangular tiles are laid are needed. The usual reference line is a longitudinal or transverse curve on ship hull surface, typically, the waterline or rib line. Either centerline method or sideline method is used to lay rectangular tiles as shown in Fig.1.
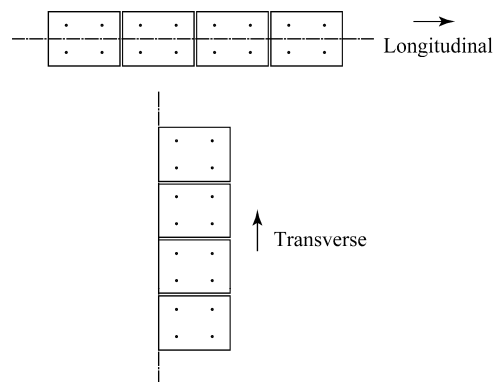

Fig.1 Laying method of rectangular tiles

The rectangular tile is resilient when deformed. For every rectangular tile, four studs are welded on the outer surface of ship hull to position the tile. Moreover, the rectangular tile is adhesively bonded to hull surface. Gaps between the

rectangular tiles are filled with sealing putties. The curvature of ship hull is various and the deformation of the rectangular tile is large when it is laid where the curvature is large. Furthermore, as a result of the large elastic deformation, it is difficult to assure a good bonding quality (Pei and Xu, 2001). Thus, it could be one of the reasons that cause the rectangular tiles to fall off and later maintenance might be required. It is discovered that the deformation of one rectangular tile varies with the direction along which the rectangular tile is laid. It follows that the deformation of the rectangular tile is the evaluation criterion of the reference line.

For a point r on a complex surface of ship hull, there is a normal vector $\boldsymbol{n}$ at it. There are infinite osculating planes through $\boldsymbol{n}$ and the direction of the osculating plane is determined by θ. The normal section is the intersection line of the osculating plane and the surface and the direction of it is also determined by θ. Then a rectangular tile with its centroid at r is laid along the normal section. The four vertices of the rectangular tile are denoted by A, B, C, and D and the normal displacements of A, B, C and D relative to r are denoted by d_A, d_B, d_C and d_D. The maximum value of d_A, d_B, d_C and d_D is denoted by d_{max} and the average value of them is denoted by d_{avg}. The maximum deformation of the rectangular tile is expressed by d_{max} and the average deformation of it is expressed by d_{avg}. Based on calculation, it could be found that both maximum deformation and average deformation of the rectangular tile are the smallest when $\theta=120º$. In other words, with the smallest deformation the rectangular tile is laid along the principal direction corresponding to the smaller value of the principal curvatures.

The length of the rectangular tile is denoted by L and the width of it is denoted by W. Let L=800 mm and W=600 mm. Fig.2 shows that such rectangular tile is laid with its centroid at the point r(0.5,0.5) along the normal section when $\theta=60º$. As shown in Table 1, the displacements of the four vertices of the rectangular tile are obtained when θ is assigned from 0º to 180º with the step size being 15º. The maximum value and the average value of the four displacements are then calculated for each θ. Fig.3 shows the plot of d_{max} and d_{avg} versus θ. An examination of Fig.3 indicates that the deformation of the rectangular tile is the smallest when it is laid along the principal direction corresponding to the smaller value of the principal curvatures. Thus, it is favorable that the reference line extends along the principal direction mentioned above.
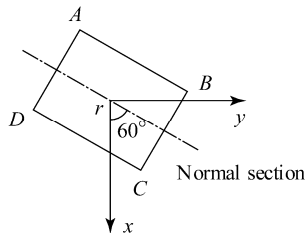

Fig.2 Rectangular tile laid along normal section

Table 1 Displacement of four vertices of the rectangular tile laid along different reference lines

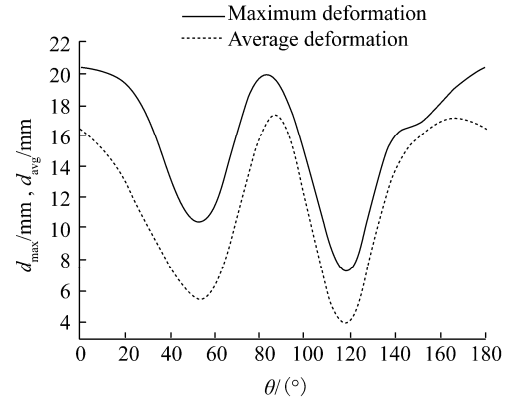| θ/(º)	d_A/mm	d_B/mm	d_C/mm	d_D/mm
0	−13.98	18.56	−13.03	20.39
15	−10.71	17.40	−8.87	19.87
30	−5.85	14.54	−3.35	17.16
45	1.02	9.50	3.63	11.57
60	9.98	1.55	11.65	2.20
75	18.63	−8.76	17.95	−9.87
90	18.85	−15.87	16.24	−16.77
105	6.40	−12.06	5.08	−10.53
120	−7.34	−1.22	−6.54	1.44
135	−14.68	8.67	−13.27	10.55
150	−16.76	15.23	−15.83	15.73
165	−15.83	18.92	−15.79	18.11
180	−13.08	20.38	−14.02	18.57

Fig.3 Deformations of rectangular tile laid along different reference lines

3 Size optimization of rectangular tile

3.1 Curvature analysis of the surface

As mentioned above, both the maximum deformation and the average deformation are the smallest when the rectangular tile is laid along the principal direction corresponding to the smaller value of the principal curvatures. This method of laying rectangular tiles is the most favorable.

For a point P on the surface, its normal curvature (Wu and Yin, 2002) could be calculated by

$$k = \frac{L + 2M\lambda + N\lambda^2}{E + 2F\lambda + G\lambda^2} \tag{1}$$

where E, F, and G are the first fundamental quantities of the surface and L, M, N are the second fundamental quantities and λ denotes the direction of the osculating plane.

It follows that the extreme values of the normal curvatures could be derived by

$$\begin{cases} k_1 = H + \sqrt{H^2 - K} \\ k_2 = H - \sqrt{H^2 - K} \end{cases} \quad (2)$$

where $K = \dfrac{LN - M^2}{EG - F^2}$ and $H = \dfrac{EN - 2FM + GL}{2(EG - F^2)}$.

The mean curvature denoted by H could be calculated by

$$H = \frac{1}{2}(k_1 + k_2)$$

The overall degree of bending of the surface is characterized by H. The mean curvature at any position on the surface is obtained, and the color filled contour map is plotted in Fig.4.
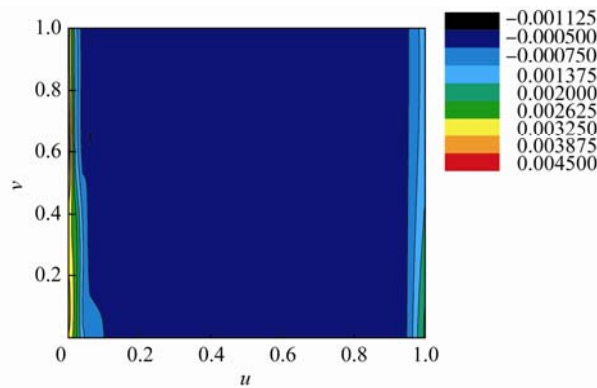

Fig.4 Contour map of mean curvature

According to the distribution of the mean curvature, the surface is divided into three layout areas which are shown in Fig.5.
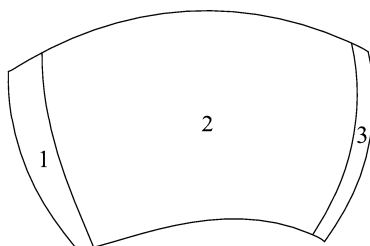

Fig.5 Three layout areas

For every area divided, a set of curves on the surface should be determined for laying rectangular tiles. As mentioned above, each curve extends along the direction corresponding to the smaller value of the principal curvatures. As seen in Eq.(1), λ is equal to λ_1 or λ_2 when k is equal to k_1 or k_2. Let k_2 be the smaller value of the principal curvatures. λ_2 denotes the direction corresponding to the smaller value of the principal curvatures. λ is defined as follows:

$$\lambda = \frac{\mathrm{d}v}{\mathrm{d}u}$$

The relationship between dv and du is expressed by

$$\mathrm{d}v = \lambda \mathrm{d}u$$

The point located in the direction of the smaller value of the principal curvatures of an initial point $r_0(u_0, v_0)$ could be expressed by $r_1(u_0 + s, v_0 + \lambda_2 s)$, where s denotes the step. Similarly, r_2 could be obtained from r_1. Then, a set of discrete points are obtained. $r(0.2, 0.2)$, $r(0.5, 0.5)$ and $r(0.5, 1)$ are selected as the initial points. Three sets of discrete points are displayed in Fig.6.
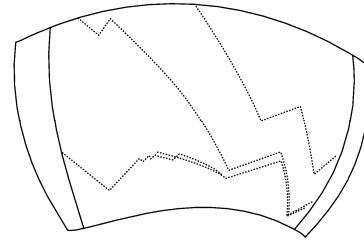

Fig.6 Three sets of discrete points

In the uv plane, linear fitting to the three sets of discrete points is carried out. The line obtained is then discretized. Finally, the NURBS interpolation (Jiang and Lei, 1995; Wu and Lu, 2001) curves are plotted in Fig.7.
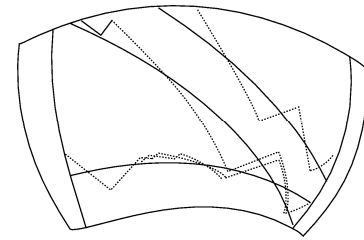

Fig.7 NURBS interpolation curves

The rectangular tiles should be laid along the NURBS interpolation curve.

3.2 Calculation of deformations of rectangular tiles of different size laid on the surface

Generally, an allowable maximum deformation is given to the rectangular tile and the deformation of laid tile should be smaller or equal to it. Otherwise, the rectangular tile could not meet the laying standard. If the maximum deformation condition is satisfied where the curvature is the largest, all the deformations of the rectangular tiles laid on each area of surface are not larger than the allowable deformation.

The deformation of the rectangular tile is various with the size of the rectangular tile. An optimum size of the rectangular tile including the length, width and length to width ratio is needed for the layout design. What we are concerned with is the allowable maximum deformation and the area of the rectangular tile, that is, the deformation of the rectangular tile should not be larger than the allowable maximum deformation and the area of it should be as large

as possible. The larger the area of the rectangular tile, the smaller the number of the rectangular tiles needed is. On the contrary, the smaller the area of the tile, the larger the number of the tiles is. The laying workload is influenced by the number of fixing bolts and the amount of stuffing between rectangular tiles. Fig.8 shows that the number of fixing bolts and the area of stuffing increase with the decrease of the area of the rectangular tile.
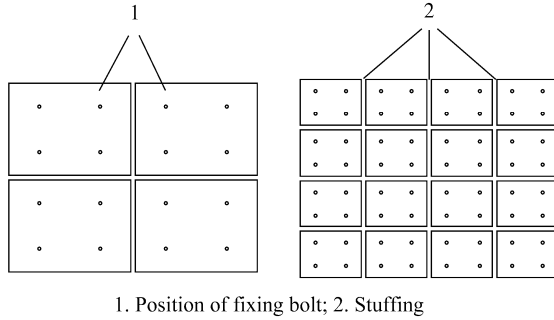

1. Position of fixing bolt; 2. Stuffing

Fig.8 Comparison of rectangular tiles of different sizes

Chen's generation algorithm is used to lay the rectangular tiles. First, the rectangular tiles are laid on the flattened surface. The planar rectangular tiles are then mapped to the original curved surface. Let the rectangular tiles to be laid on the above surface be whole and no cut rectangular tiles are used. The rectangular tiles of various sizes are laid along the principal direction corresponding to the smaller value of the principal curvatures where the curvature is the largest in each layout area. On this occasion, the maximum deformation of the rectangular tile is the largest. The deformations of the rectangular tiles of different sizes laid on in area 2 are shown in Table 2 with the length to width ratio of the rectangular tile being 1.0.

Table 2 Deformations of rectangular tiles of difference sizes

Size/mm×mm	d_A/mm	d_B/mm	d_C/mm	d_D/mm
450×450	2.79	0.46	2.82	1.49
500×500	3.44	0.36	3.49	1.91
550×550	4	0.9	4.1	2.56
600×600	4.53	2.49	4.72	3.39
650×650	5.21	5.41	5.47	4.22
700×700	5.98	10.52	6.33	5.09
750×750	7.3	17.96	7.6	5.61
800×800	8.9	29.59	9.08	6.02

Simulation experiment of laying the rectangular tiles of various lengths, width and length to width ratios in this area is conducted and the deformations of the tiles are then obtained. As shown in Fig.9, the curves of the maximum deformation versus the length of the rectangular tile are plotted with different length to width ratios.
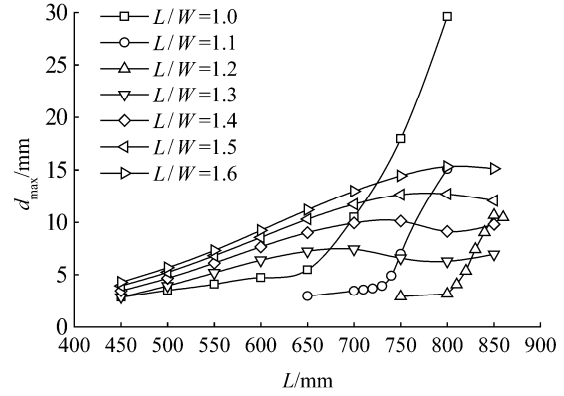

Fig.9 Curves of local maximum deformation versus length of the rectangular tile

3.3 Size optimization of rectangular tile

Let the allowable maximum deformation of the rectangular tile be m. It could be seen that there is an allowable maximum size of the rectangular tile corresponding to a specified length to width ratio. For m=5 mm, the allowable maximum size and area (denoted by S) of the rectangular tiles of various length to width ratios are shown in Table 3.

Table 3 Allowable maximum size of rectangular tile of different length to width ratios

L/W	L/mm	W/mm	S/mm^2
1.0	616.29	616.29	$3.798×10^5$
1.1	739.84	672.58	$4.976×10^5$
1.2	823.44	686.20	$5.651×10^5$
1.3	525.46	404.20	$2.124×10^5$
1.4	517.56	369.68	$1.913×10^5$
1.5	501.51	334.34	$1.677×10^5$
1.6	474.79	296.74	$1.409×10^5$

It could be found in Table 3 that the area of the rectangular tile varies with the length to width ratio under the condition of allowable maximum deformation. When L/W=1.2, the area of the rectangular tile is the largest and it is the most favorable for the layout in terms of the number of fixing bolts and the amount of stuffing to be used. Therefore, 1.2 could be the optimum length to width ratio of the rectangular tile. It follows that the optimum size of the rectangular is obtained: L/W=1.2, L=823.44 mm, W=686.20mm and S=5.651×10^5 mm^2.

Based on the above analysis, the rectangular tiles with the optimum size are used for the layout design so it could be assured that the deformations of the tiles are not larger than the allowable maximum deformation and the workload of installing them is the lightest. The optimum size of the rectangular tile for the other two layout areas could be obtained as well.

Typically, the surface of aft hull section is selected. The

surface is divided into three layout areas. For each area, the optimum size of the rectangular tile is obtained by means of the above process. Consequently, the layout design drawing is obtained. Fig.10 partially shows the layout design drawing between area Ⅰ and area Ⅱ.
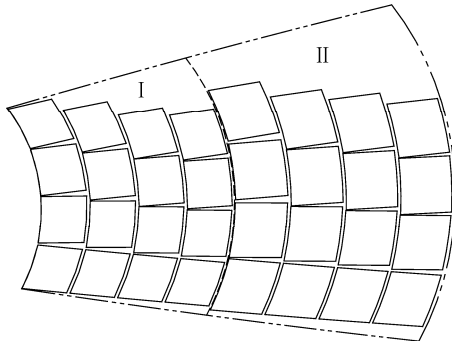

Fig.10 Part of layout drawing

4 Conclusions

In this paper, a new method for the layout design of rectangular tiles on ship hull is presented. The ship hull surfaces of different curvatures are treated differently. This method of laying rectangular tiles could assure good layout quality. Concretely, some beneficial conclusions are drawn:

1) With the smallest deformation, the rectangular tile should be laid along the direction corresponding to the smaller value of the principal curvatures.

2) For various curvatures, the ship hull is divided into different areas for the layout. Where the curvature is larger the rectangular tile of bigger size is laid and vice versa.

3) With the allowable maximum deformation condition satisfied, for every layout area the optimum size of the rectangular tile is obtained in terms of the number of fixing bolts and amount of stuffing.

This laying mode could make the gap between rectangular tiles too large and not uniform and in addition, large amount of stuffing is needed for the layout. As a result, the layout design is of poor quality. When the rectangular tiles are laid along the reference lines which are equidistant curves on ship surface, the gap between the tiles could be effectively controlled. Moreover, ship hull could not be completely covered if we only use whole rectangular tiles. As a solution, the cut rectangular tiles are used for the layout design.

References

Chen Zhibiao, Zhao Yao, Yan jun (2006). Computerized three-dimensional design system for rectangular tile coating on hull surface. *Journal of Marine Science and Application*, **5**(2), 13-18.

Chen Zhibiao, Zhao Yao, Yan Jun (2007a). Flattening of flexible coating block on ship hull. *Journal of Engineering Graphics*, **27**(1), 119-123. (in Chinese)

Chen Zhibiao, Zhao Yao, Yan jun (2007b). Generation of rectangular tile on ship hull. *Journal of Engineering Graphics*, **28**(1), 83-88. (in Chinese)

Guo Rensheng, Su Jun, Lu Hongsheng (2003). *Application of optimal design*. Beijing Publishing House of Electronics Industry, Beijing, 13-26. (in Chinese)

Jiang Shoushan, Lei Yaping (1995). An explicit algorithm for NURBS interpolations. *Journal of Xi'an Institute of Technology*, **15**(4), 260-265. (in Chinese)

Kaveh A, Shahrouzi M (2006). Simultaneous topology and size optimization of structures by genetic algorithm using minimal length chromosome. *Engineering Computations*, **23**(6), 644-674.

Pei Yongxiang, Xu Jing (2001). The use of microwave bridge to inspect disbonds of anechoic tiles on submarine. *Journal of Xinjiang Normal University*, **20**(1), 26-29. (in Chinese)

Pugsley G, Chillet C, Fonseca A (2006). Cost - performance - size optimization for automotive induction machines: a fast and accurate FEM, analytical model and optimization mixed procedure. *Compel*, **25**(2), 297-308.

Wu Jie, Gong Ming, Zhang Qilin (2007). Optimal distribution of planar glass in arbitrary spatial surface curtain wall based on ObjectARX. *Computer Aided Engineering*, **16**(3), 22-29. (in Chinese)

Wu Nengzhang, Yin Yang (2002). Analysis of rake face normal curvature of ball-nose end mill tool. *New Technology & New Process*, (4), 19-20. (in Chinese)

Wu Xiaoyan, Lu Xilin (2001). The reconstruction technique of NURBS-based 3D-mannequin with dense data points. *Journal of Beijing Institute of Clothing*, **21**(2), 45-52. (in Chinese)

Yu Chongwen, Wang Jun, Wang Xinhou (2003). *Optimal design of engineering parameters*. Publishing House of Donghua University, Shanghai, 129-147. (in Chinese)
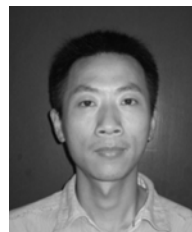
Nian-qing Wu was born in 1981. He is a PhD candidate at Huazhong University of Science and Technology. His current research interests include computer graphics, CAD/CAM and enterprise informatization.

Yao Zhao was born in 1958. He is a professor at Huazhong University of Science and Technology. His current research interests include computational mechanics, structural static and dynamic response, *etc*.
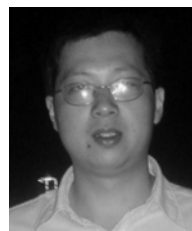
Hua Yuan was born in 1977. He is a PhD candidate at Huazhong University of Science and Technology. His current research interests include computer graphics, CAD/CAM and enterprise informatization.