OPTIMIZATION OF ORIENTED NESTING LAYOUT ON RECTANGULAR MATERIAL SHEETS

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ABSTRACT: *This article introduces research results on optimization of oriented nesting layout for pieces of irregular shapes to be cut in rectangular material sheets in order that number of cut pieces is maximized or material waste is minimized. The optimized alternative is selected when material utilization coefficient is maximized with the requirement on strain, texture, fiber orientation of material sheet. This solution may be applied in some industries using sheet material and having requirement on orientation when cutting .*

Keywords: *oriented nesting, material utilization coefficient, material utilization coefficient.*

1. INTRODUCTION

For pieces to be cut from sheet material in wood processing and other industries, the texture, or aesthetical requirements, or mechanical properties requirements may place certain constraints on orientation of the piece on the sheet and in this case the choice of the optimal layout scheme cannot cover the free rotation of the piece around its pole as it is the case of non-oriented pieces layout scheme.

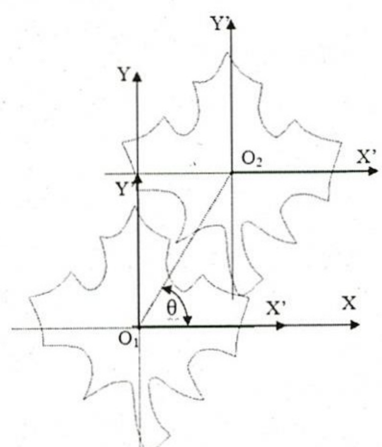

Fig.1. The Piece S_2 rotating an angle φ around pole O_1

For economy of material in the layout scheme of oriented pieces, the cutting operation must be performed after the optimal layout scheme minimizing cutting scrap is determined. For this reason research on optimal nesting problems and automation of the stamping process is a primary concern of manufacturers.

In industrial production the layout scheme of parallel translation (fig. 3) is preferred for high material utilization efficiency and convenient standardization of preparation and cutting operations.

When the pieces are cuts without orientation on the sheet material like sheet synthetic material, sheet metal, synthetic leather …, the optimal layout scheme is chosen so that the number of pieces per sheet is maximized at any rotation angle φ around the pole O (θ can range from 0^0 to 360^0) like on fig.1. But when the pieces are cuts with certain orientation (fig. 2) that is necessary for mechanical properties of the pieces or for ornament pattern, or for texture of the sheet material like printed fabric, woven fabric…, then the layout scheme does not allow but certain default oriented angle φ (φ is fixed). The optimal nesting problem is in this case called *"Optimal layout scheme when oriented pieces are cut from sheet material of fixed one side edge"*.

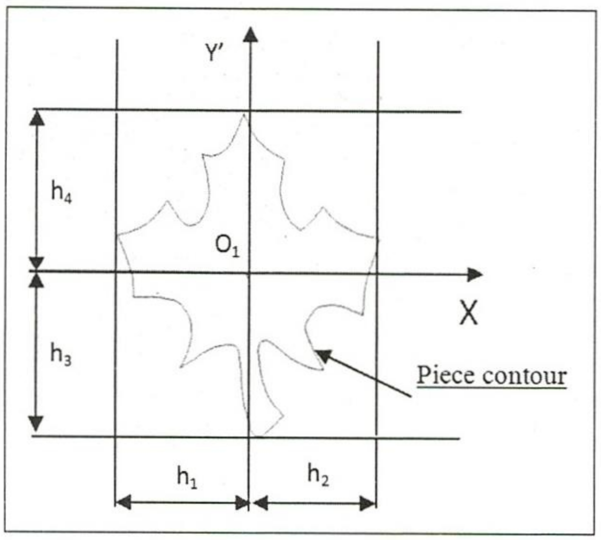

Fig. 2. Position of default angle and dimensions of piece

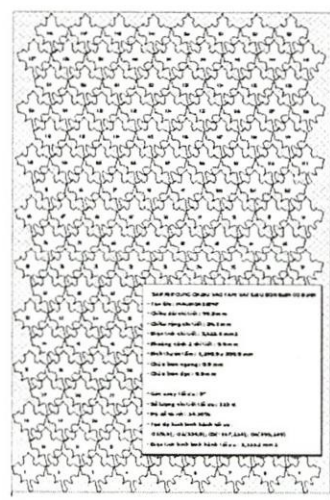

Fig. 3. Layout scheme of oriented identical pieces

Mathematical foundations for solution of optimal nesting problems are presented in references [5], [6], [7], [8]. Piece contour is described and digitalized into computer [6]. The system of parallel translation of the layout scheme is characterized by godographs [8]. Algorithm determining conditions of non-intersection of pieces and conditions of fitting into the material area is presented in reference [5].

For resolving this problem on computer, it is necessary to find the algorithm for optimal layout scheme of oriented pieces on sheet material of fixed one side edge, specifically of rectangular shape, with the objective of maximizing the number of pieces per sheet and minimizing the cutting scrap so as to ameliorate material utilization efficiency and to reduce operating cost.

2. FORMULATION OF PROBLEM

The problem of arranging identical oriented pieces on sheet material can be formulated like this:

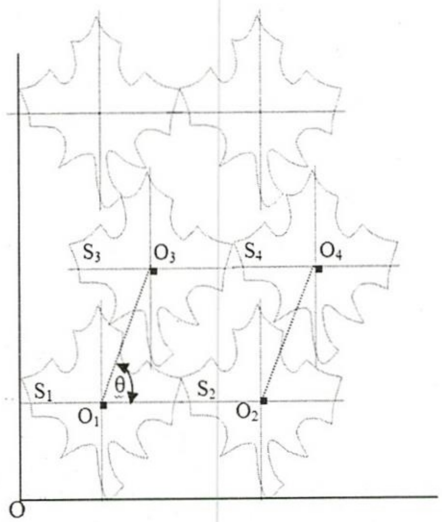

Fig. 4. Position of 4 pieces in the layout scheme

Given a combination of identical pieces S_i and a material area limited by the rectangle ABCD of length L and width H, to find the arrangement of identical oriented pieces into the rectangle ABCD so that the utility coefficient (UC) is highest which mean that the number of obtained pieces is maximized.

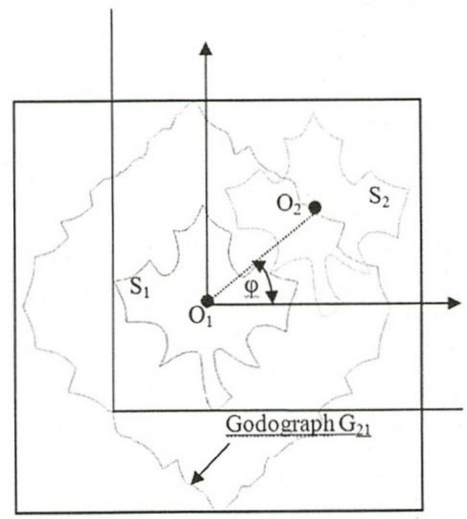

Fig. 5. Godograph of the piece

3. ALGORITHM FOR SOLUTION OF PROBLEM

The criteria of economy of the layout scheme is UC, denoted as η, which is calculated as:

$$\eta = \frac{F_0}{F_p}.100\%$$

Where: F_0 – Area of n pieces (Fo = n*S) ;

S - Area of one piece;

Fp – area of material sheet (Fp = LxH);

n – Number of arranged pieces.

Number of arranged pieces depends on angle θ between axis O_1O_2 and axis OX as illustrated on fig. 5.

To each position of the piece S, one coordinate system X'OY' is attached. The support distances h_1, h_2, h_3, h_4 are determined as in fig. 2. The said distances are called support distances and determine the arranging area Ω which is limited by the rectangle O_1KMN (fig. 6). All coordinates of poles O_i of pieces arranged in this area have the condition of fitting into the material sheet ensured.

The algorithm for finding optimal layout scheme in this case consits of the following steps:

1. Place the piece S_1 into the position tangent with two edges AB and AC of the material sheet. The pole O of the coordinate system XOY is placed into the point A (fig. 6). Consequently, coordinates of the pole O_1 of the piece are determined as $O_1(X_1,Y_1)$ as $O_1(h_1,h_3)$. In the system of parallel translation of the layout scheme, the condition of non-intersection of pieces requires that the pole of the piece S_2 will lie on the concurrent godograph of the piece S_1 and must fall into the area Ω (O_1KMN). For this reason for determining the position of pole O_2, the concurrent godograph G_1 of the piece S_1 must be constructed and the point set R_1, $R_2,\ldots,R_j,\ldots,R_k$ of the godograph G_1 and falling into the area Ω must be found.
2. Construct the piece S_2 by placing its pole O_2 one by on into the position of the point set R_1, $R_2,\ldots,R_j,\ldots$, R_k. At each position of S_2 the coordinate of pole $O_2(X_2,Y_2)$ will be determined.
3. Determine the position of the piece S_3 by the principle of the most compact arrangement into the basic parallelogram, to construct concurrent godograph G_2 of the piece S_2 with pole O_2. Then intersection of the two godographs G_1 and G_2 is the position of the pole O_3 of the piece S_3. The position of O_3 must satisfy the condition of falling into the area Ω. At this position the coordinates of pole $O_3(X_3,Y_3)$ are determined.
4. The position of the piece S_4 is determined by constructing the parallelogram $O_1O_2O_3O_4$ whose three vertices are determined as O_1, O_2, O_3. Pole O_4 of the piece S_4 must likewise satisfy the condition of falling into the area Ω. At the position of S_4, the coordinates of pole $O_4(X_4,Y_4)$ are determined.
5. By recursion on four poles $O_1(X_1,Y_1)$, $O_2(X_2,Y_2)$, $O_3(X_3,Y_3)$, $O_4(X_4,Y_4)$ in the area Ω, count the number of pieces arranged in the material sheet [7]. Consider all options where position of pole O_2 of the piece S_2 is placed into the point set R_1, $R_2,\ldots,R_j,\ldots$, R_k. Among all considered options the chosen optimal one is the one having most arranged pieces.

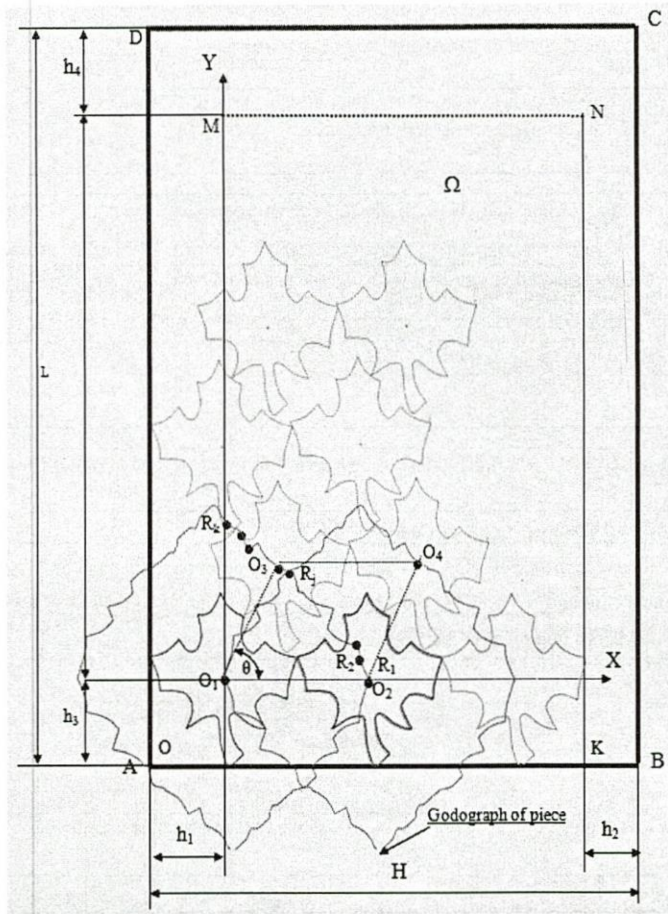

Fig. 6. Arrangement of oriented pieces on sheet material

The algorithm for optimal arrangement is represented in figure 7.

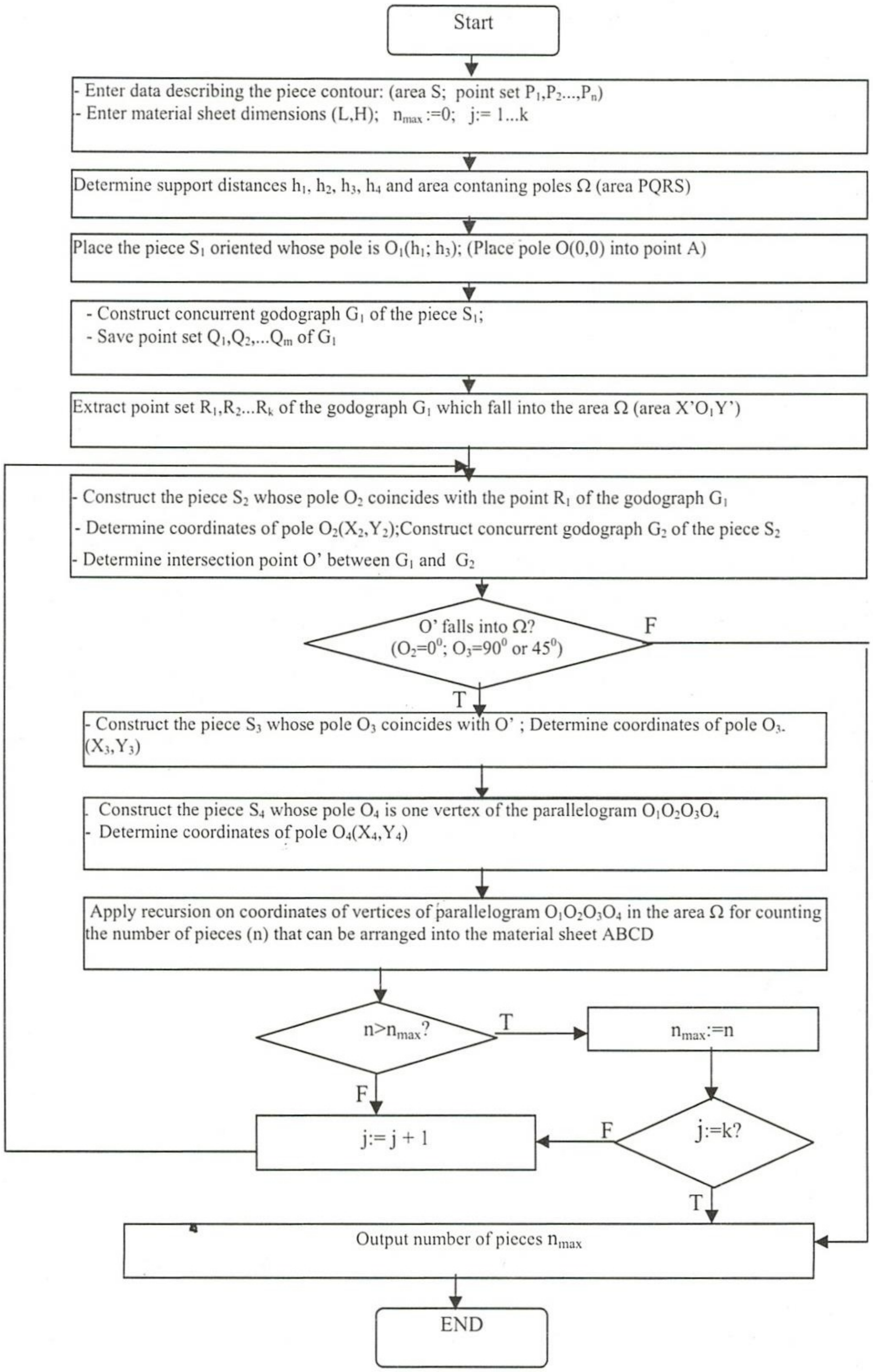

Fig. 7. Algorithm for optimal layout scheme of identical oriented pieces

4. SOFTWARE FOR OPTIMAL CUTTING SCHEME

The software is written according to the above algorithm in the language Delphi and includes description of the sample piece contour by digitalizing the piece contour into the computer from its scanner picture or other descriptive software. The figures 8 and 9 show the application of the software.

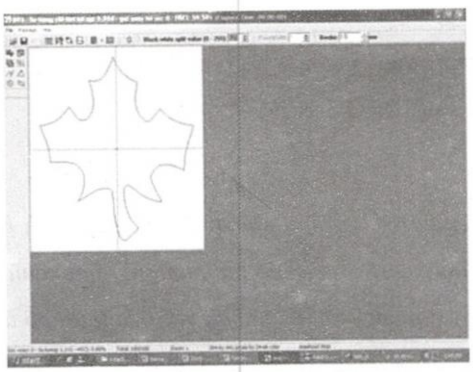

Fig. 8. The sample piece contour is digitalized into the computer

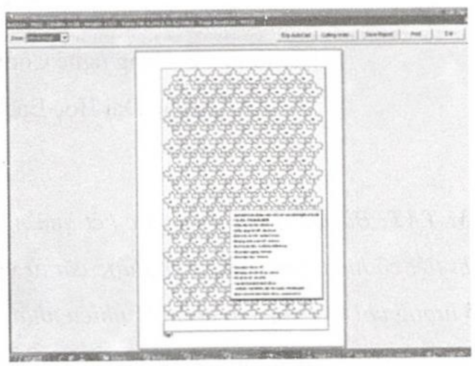

Fig. 9. Arrangement by software

Table 1. Application of the software

Sample piece contour	Data describing the piece		Data describing the material sheet	Arrangement by software	
	Width (mm)	86,1	The material sheet of rectangular shape has length L and width H (LxH: 1200mm x 800mm)	- Number of arranged pieces:	153.
	Length (mm)	99,8		- Coefficient of utility	54,56 %
	Area (mm^2)	3.423,4			

5. CONCLUSION

Research on optimal layout scheme of identical oriented pieces on sheet material of limited one side edge, specifically of rectangular shape, has provided algorithm for maximum material utilization coefficient in case the pieces of arbitrarily complex shapes are to be arranged for cutting. The knowledge of the maximum material utilization coefficient has theoretical and practical significance in replacing previous manual solution of layout

problems. This is also the basis for building application software that will be incorporated into CNC machines for automation of pressing operations in certain industries, pursuing the objective of material saving, cost reduction and productivity enhancement.

TỐI ƯU HÓA SƠ ĐỒ SẮP XẾP CÓ ĐỊNH HƯỚNG TRÊN TẤM VẬT LIỆU HÌNH CHỮ NHẬT

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TÓM TẮT: *Bài báo giới thiệu các kết quả nghiên cứu về tối ưu hóa sơ đồ sắp xếp định hướng một loại chi tiết có hình dạng phức tạp được cắt từ vật liệu dạng tấm có có hình dạng là hình chữ nhật, sao cho số lượng chi tiết sắp xếp được là nhiều nhất, hay nói cách khác là phần vật liệu thừa bỏ đi là ít nhất. Phương án tối ưu được lựa chọn tương ứng với hệ số sử dụng vật liệu lớn nhất với yêu cầu về độ bền cơ học, tính chất hoa văn, thớ sợi,... cần phải theo một hướng của tấm vật liệu. Giải pháp này có thể được áp dụng cho một số ngành công nghiệp sử dụng vật liệu dạng tấm và có yêu cầu định hướng khi cắt vật liệu.*

Từ khóa: *tối ưu hóa sơ đồ, vật liệu dạng tấm*

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