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Modeling of Complex Fabric Structures by Methods of Computer Simulation

Karmaşık Yapılı Kumaşların Bilgisayar Simülasyonu Yöntemleriyle Tasarlanması

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MODELING OF COMPLEX FABRIC STRUCTURES BY METHODS OF COMPUTER SIMULATION

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***ABSTRACT*:** Fabric quality, which may be defined as the satisfaction obtainable from required performance properties manifesting themselves in fabric usage, is a consequence of its physical structure. It is imperative that this structure shoud be stable during a resonable life of the fabric. Principles of design to define fabric structure satisfying these needs are quite well known and computer aided fabric design applications are widespread. In the case of design of fabrics of complex structure, however, there arise many problems and the current computer aided design software may not be adequate to cope with them. In this paper some important problems encountered in the design of simple and complex fabric structures are discussed in general, based on relevant literature. Three examples are given how they may be solved mathematically in a suitable way for computer applications to obtain computer simulations of complex fabric structures such as double woven fabrics, woven carpets and rib knit fabrics.

Keywords: Fabric geometry, yarn cross sectional shape, yarn path curve, loop shape, dimensional stability

KARMAŞIK YAPILI KUMAŞLARIN BİLGİSAYAR SİMÜLASYONU YÖNTEMLERİYLE TASARLANMASI

***ÖZET*:** Kumaşın, kumaştan beklenen ve kullanımı sürecinde kendini ortaya koyan performans özelliklerince sağlanan tatmin duygusu olarak tanımlanabilen kalitesi fiziksel yapısının bir sonucudur. Bu yapının kumaşın kabul edilebilir bir kullanım süresi içinde değişmez kalması temeldir. Bu istekleri karşılayan kumaş yapısının tanımlanması anlamındaki tasarım ilkeleri iyi bilinmekte olup, bilgisayar destekli kumaş tasarım uygulamaları oldukça yaygındır. Karmaşık yapılı kumaşların tasarımı durumunda ise, bir çok problem ortaya çıkmaktadır ve var olan bilgisayar destekli tasarım yazılımları bunların çözümünde yetersiz kalabilirler. Bu makalede basit ve karmaşık yapılı kumaş tasarımında karşılaşılan bazı önemli problemler ilgili literatür ışığında incelenmektedir. Bunların, çift katlı dokuma kumaşlar, dokuma halılar ve ribana örme kumaşlar gibi karmaşık kumaş yapılarının bilgisayar simülasyonlarını elde etmek amacıyla, matematiksel olarak ve bilgisayar uyarlamalarına uygun biçimde, nasıl çözülebileceğini gösteren üç örnek verilmektedir.

Anahtar sözcükler: Kumaş geometrisi, iplik kesit biçimi, iplik yol eğrisi, ilmek biçimi, boyut dayanıklılığı

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1. INTRODUCTION

Fabric quality is identified by those properties such as strength, firmness and flexibility, a uniform surface with good cover, appropriate weight and thickness, and stability of structure termed as "dimensional stability". These properties depend as well on fabricstructure as on yarn properties.

Yarn properties which affect fabric performance are fibre type, yarn structure, yarn count and twist, together with mechanical properties characterised by yarn extensibility, rigidity, compressibility and strength. The fabric structure, on the other hand, is mainly defined by yarn diameter, fabric sett and weave type. These are structural parameters which define what is called "fabric geometry". Structural parameters are the principle design parameters which, in consequence, define also the fabric quality and performance.

Fabric structure is formed by the arrangement of yarns on the fabric plane as a set, being interlaced at the same time with other sets of yarns either in parallel or perpendicular direction to the previous set, depending on the fabric type as shown in Figure 1 and 2. In woven fabrics the interlacing (or intersecting) yarns are at right angles to each other, in knitted fabrics they are in the form of loops interlsecting in both directions. There are exceptions to this rule in some complex woven structures as given in Figure 3 and 4.

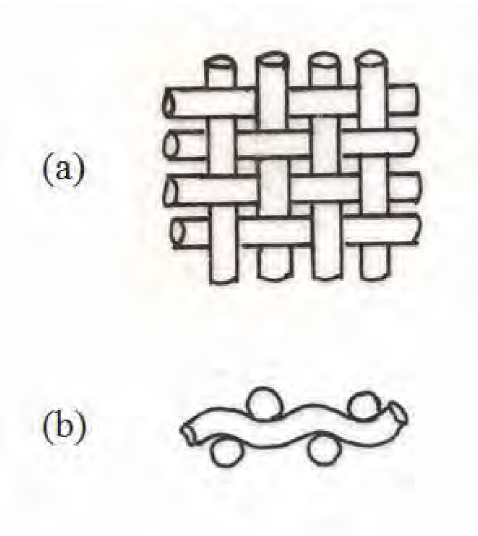

Figure 1. Geometric representation of plain woven fabric (a: plane view, b; cross sectional view)

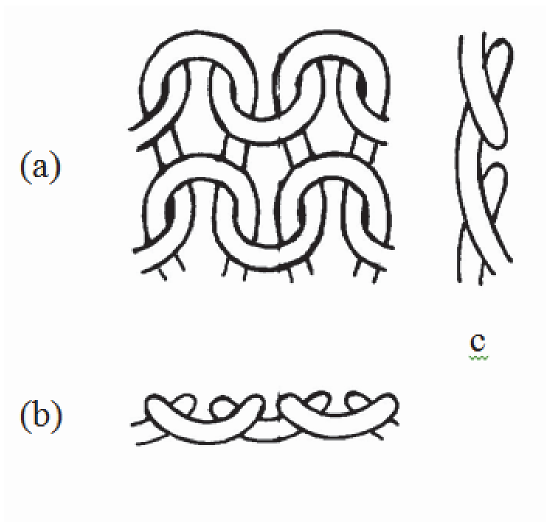

Figure 2. Geometric representation of plain knitted fabric (a. plane view, b,c cross sectional views

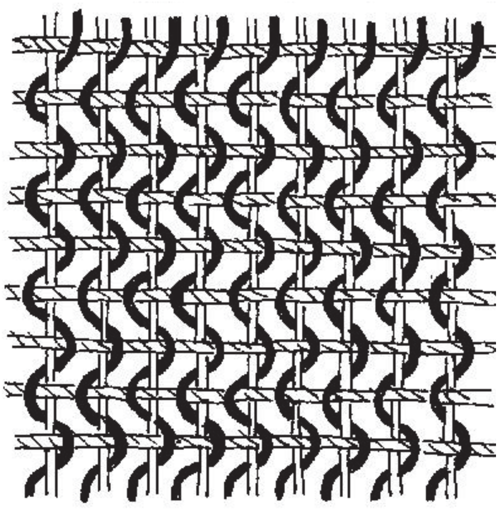

Figure 3. Gauze woven structure

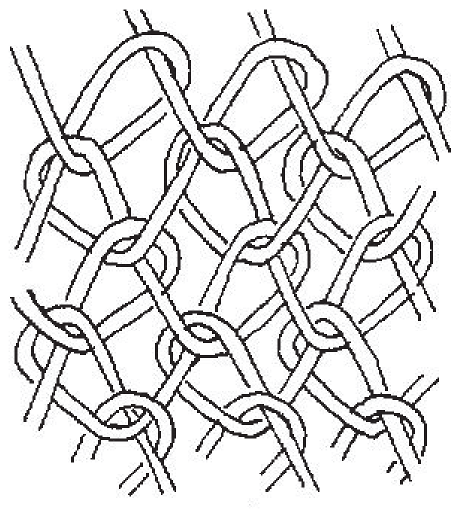

Figure 4. Warp knitted structure

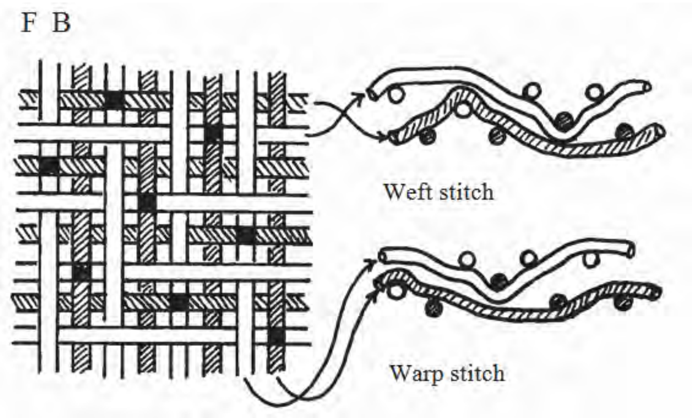

Figure 5. Representation of double woven fabric structures with 2/2 twill weave on face and back [1]

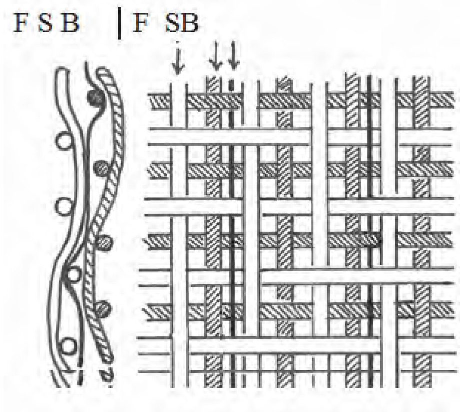

Figure 6. Centre stitched double woven fabric structure (F: Face yarn, S: Binding yarn, B: Back yarn) [1]

There are also multi layered structures in which certain yarns of one layer interlace with some yarns on the other layer as in shown in Figure 5 or fabric layers are joined together by special binding yarns as shown in Figure 6.

The movement of the binding (or stitching) yarns between layers as in double woven fabrics necessitates adequate space between neighbouring yarns for easy movement during fabric formation, in consequence causing lower setts (or greater yarn spacings) to be employed. On the other hand, yarns are not rigid structures. They are structures formed by fibres lying along the yarn with some space between them, being twisted together to give yarn strength and stability. As a consequence there is not a fixed yarn cross sectional shape nor a definite diameter. Yarns are also compressible and the yarn cross sectional shape can easily be changed by radial forces in fabric formation and after. Thus, yarn diameter is an important parameter in fabric structure and it is imperative that the cross sectional shape of the yarns have to be defined also in developing the geometrical model of the fabric structure. It influences fabric properties to a great extent such as, greater is the yarn diameter, greater is the fabric thickness and lower the fabric sett.

The stability of fabrics depend to some extent to correct thread setting (or thread density) in fabric. Fabric sett is important, also, in that it determines the stiffness, flexibility, the heat, water and air permeability, the draping and wrinkling properties of the fabric. It is generally accepted that to obtain a stable fabric with good performance properties fabric structure should be compact with minimum spaces between component yarns without unduly distorting or compressing the structure. This may be taken as a rule in developing a structural model of an ideal fabric.

In practice, however, a general model of fabric structure is built up and the conditions are searched to obtain a more compact structure. Although problems of defining a designed fabric structure mathematically are solved somehow, transforming this general geometry to a more compact structure which is compatible with yarn properties and is also mechanically feasible is not an easy task.

2. PREVIOUS WORK ON FABRIC GEOMETRY

The first plain woven fabric geometry by Peirce as shown in Figure 7 was based on the assumptions that the yarns were circular in cross section and are infinitely flexible, in consequence they took the shape of the yarn surface they were in contact with and otherwise remained straight [2].

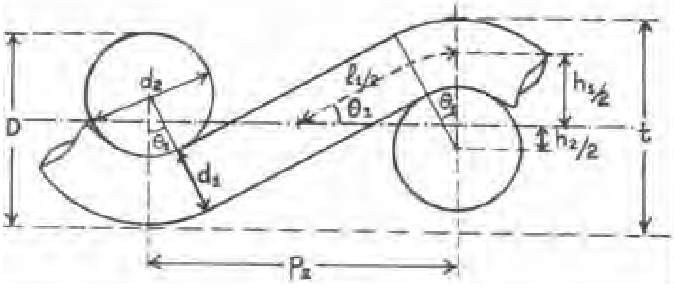

Figure 7. Peirce's circular thread plain woven fabric geometry

Peirce defined the main fabric parameters in the following equations:

$$D = d_1 + d_2 = h_1 + h_2 = H \tag{1}$$

$$t_1 = h_1 + d_1 \text{ or } t_2 = h_2 + d_2 \tag{2}$$

$$h_1 \cong \frac{4}{3} p_2 \sqrt{c_1} \quad , \quad h_2 \cong \frac{4}{3} p_1 \sqrt{c_2} \tag{3}$$

where d_1 and d_2 are the yarn diameters, h_1 and h_2 are crimp amplitudes, t_1 and t_2 are fabric thicknesses in two directions and c is the crimp defined separately for warp and weft as

$$c_1 = \frac{l_1 - p_2}{p_2} \ , \ c_2 = \frac{l_2 - p_1}{p_1} \tag{4}$$

Taking into account the flattening of yarns in fabric structure Kemp proposed a racetrack section of yarns and worked out a plain woven fabric geometry as shown in Figure 8 [3]. Here the unit length of the yarn and crimp amplitude are defined in two ways related by the equations

$$L_1^{'} = L_1 - (a_2 - b_2) \tag{5}$$

$$L_2^{'} = L_2 - (a_1 - b_1) \tag{6}$$

$$c'_1 = \frac{c_1 p_2}{[p_2 - (a_2 - b_2)]} \tag{7}$$

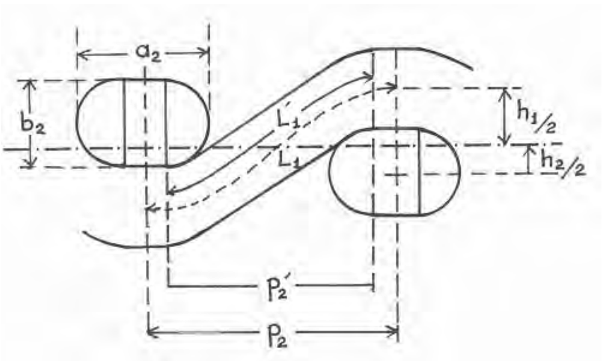

Figure 8. Kemp's plain woven fabric geometry based on race-track section [3]

In Kemp's sectional geometry yarn cross sections are defined as race-track sections formed by two semicircles with a rectangular part in between. Peirce's formulas are still applicable and the major (a_1, a_2) and minor diameters (b_1, b_2), calculated from an equivalent circular section, may be used. The calculation of major and minor diameters may be based on the assumption that either the yarn cross sectional area or the yarn perimeter remains constant during compression.

One of the major difficulties in working out a fabric geometry is the definition of yarn diameter and cross sectional shape in fabric structure. As the measurement of yarn diameter is difficult and not so reliable, Ashenhurst gave a formula to calculate it from yarn count as

$$d = \frac{1}{K\sqrt{N}} \quad \text{or} \quad d = K\sqrt{C} \tag{8}$$

where d is yarn diameter, N is yarn count in indirect count systems, C is yarn count in direct count systems and K is a convenient constant. Since yarn density will depend on fibre density and the degree of packing of fibres, the constant K will have to be defined for different fibres and different yarn production systems.

This problem was considered, in later years, by Grosberg [4] and assuming that yarn has a circular cross-section as did Ashenhurst, introduced a parameter called porosity in his theory of yarn diameter and gave the formula and suggested a porosity value of 0.65 for yarns in fabrics of normal construction [5].

$$d = 3.57/10^3 \sqrt{\frac{tex}{FibreDensity \times Porosity}} \ \text{cm} \tag{9}$$

Peirce developed also a plain knitted fabric geometry based on a structure which contained maximum amount of yarn. In his model the central axis of the yarn was wrapped around the surfaces of three cylinders being tangent in passing from one to the other and which allowed the interlacing yarns to be able to pass through inside the loops formed by the yarn. To satisfy the condition of maximum yarn in unit structure the loop tops and loop legs will be in contact in horizontal and vertical direction as shown in Figure 9 [6].

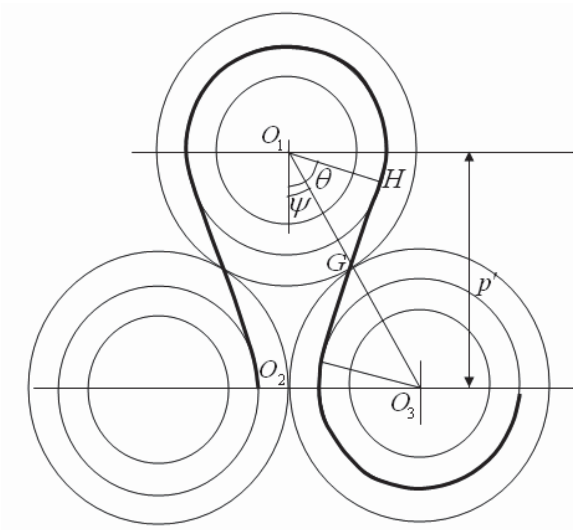

Figure 9. Peirce's plain knitted fabric geometry [6]

The radii of the cylinders on which the central line of yarns is 3/2 times the yarn diameter *d* and the spacing between loop rows (or courses) p', can be calculated from the right angled triangle $O_1O_2O_3$ as

$$p' = \sqrt{(4d)^2 - (2d)^2} = 2\sqrt{3}d = 3.464d \qquad (10)$$

The spacing between loop chains (or wales) will be determined from O_2O_3 as four times the yarn diameter. The loop length will be obtained by the addition of straight and curved parts by the formula

$$\ell = 4\left[3/2d(\pi - \theta) + 2d\sin(\theta - \psi)\right] \qquad (11)$$

Here the angle ψ is given as

$$\psi = \sin^{-1}(1/2) = 30^0 \qquad (12)$$

and from the triangle O_1HG the angle $(\theta - \psi)$ is given by

$$\theta - \psi = \cos^{-1}(1.5/2) = 41^0 \qquad (13)$$

When these values of the angles are substituted in equation (11) a formula for the loop length in terms of yarn diameter are obtained as

$$\ell = 16.6628d \qquad (14)$$

Thus, in a an ideal structure in which maximum amount of yarn is contained the yarn diameter alone will define the structure.

Following these early model development approaches of fabric geometry, there have been many works based on a model of yarn which is a flexible rod with some rigidity. This is a valid assumption since yarn segments in fabric structure are of small lengths with respect to yarn diameter and fabric structures are elastic materials formed by deformation of straight yarns into curved shaped during fabric formation processes. Peirce himself developed a woven fabric geometry [2]. To mention a few, other important works on woven fabric geometry on these lines are due to Olofsson, Grosberg and Kedia and Baser [7, 8, 9]. For knitted fabrics works of Leaf, Munden, Grosberg, Hepworth and Leaf, de Jong and Postle and Kurbak are worth mentioning [10, 11, 12, 13, 14, 15]. The mathematical treatments in these works are highly complicated and do not always give satisfactory results to be employed in practical use.

In the early works on structural models of woven fabrics general geometrical models have been developed and for a tighter or more closely set fabrics special conditions have been imposed on these general models. Kemp's model shown in Figure 8 is an extension on Pierce's model allowing for yarn flattening. In Love's work geometries of highly set fabrics called as jammed structures are developed and in Hamilton's work both the effect of high set (or high yarn density) and of cross sectional change due to weave structure are taken into account [16, 17]. In knitted fabric geometry researches, hovewer, although the eearly model of Peirce aimed at a fabric of maximum tightness, later research, especially those based on flexible yarn assumption as Munden's, aimed to develop a geometry of fabric in relaxed condition and, also, in some exraneous conditions imposed on this [6, 11].

3. WORKS ON COMPLEX FABRIC GEOMETRIES

For design purposes the weight and thickness of the fabric depend on fabric geometry and the main structural parameters are yarn counts and yarn densities (settings) to give a woven fabric with a certain weave structure and of a given unit weight. Likewise, for simple knitted constructions yarn count and loop densities are the main structural parameters. There are practical rules and standard tables to design such fabrics and the required yarn consumption can be calculated. For complex structures, however, practical and reliable rules do not exist and accepted fabric geometries have not, in general, been worked out. It is, therefore, an extensive research field to develop complex fabric geometries for design purposes.

An early research to define structural parameters of double fabrics is the treatment by Berkowitsch [18]. The settings to be applied to double fabrics relative to single fabric were discussed in this work rather than develping a double fabric structural model. Development of fabric geometries for various types of carpet structures to calculate unit yarn consumptions was undertaken by Baser, Kırtay and Onder and revised later by Baser [19, 20].

For complex knitted fabrics the early works are due to Smirfitt (1965) and to de Jung and Postle for 1x1 rib fabric structure [21, 14]. There are, however, more and numerous complex knitted structures. Kurbak and his collegues have developed complex fabric geometries for some of the more complex weft knitted structures. They heve, all, been based on Kurbak's plain knitted fabric model which he adopted first to 1x1 rib structure [15, 22].

In woven fabric geometries it is generally sufficient to define the cross sectional geometry of yarns in planes paralel to warp and weft yarns. In knitted structures, however, plane view together with the cross sectional views in the direction of courses and wales and sometimes in the thickness direction will have to be defined. The geometrical requirement is that the intersecting yarn surfaces will not intersect each other, being apart or tangent, and in tight structures they will be in contact as tangent surfaces. Furthermore, yarn flattening will have to be considered and defined in terms of major and minor yarn diameters under varying conditions. In the present paper three examples are described in which these conditions are simulated in computer medium by algebraic and graphical methods.

3.1 Geometry of a Double Weft Wire Wilton Carpet Structure

Carpet structures are formed by inserting yarn pieces perpendicular to fabric surface creating what is called a pile surface. This pile surface is obtained by cutting the pile yarn inserted into the structure in the form of loops by some method. It is generally accepted that the quality of carpet correlates with a high pile density, apart from the quality attributes imparted by raw material used, mainly of the pile yarn.

The pile surface of double weft wire Wilton carpet structure as shown in Figure 10 at maximum set is formed by pile yarns making loops over metal wires inserted into the fabric structure like a pick (weft yarn) between every two weft yarns. These loops are later cut over at the withdrawal of these tools carrying a razor at their ends. The unit structure is composed of two warp yarns, two weft yarns, a straight filling yarn and one pile loop. The cross sectional shape of warp, weft and filling yarns are assumed to be circular, the pile yarn is assumed to be subjected to flatenning and to follow a semi-circular arc over the wire top. The wires rest at a level allowed by the warp yarns and determine the pile length.

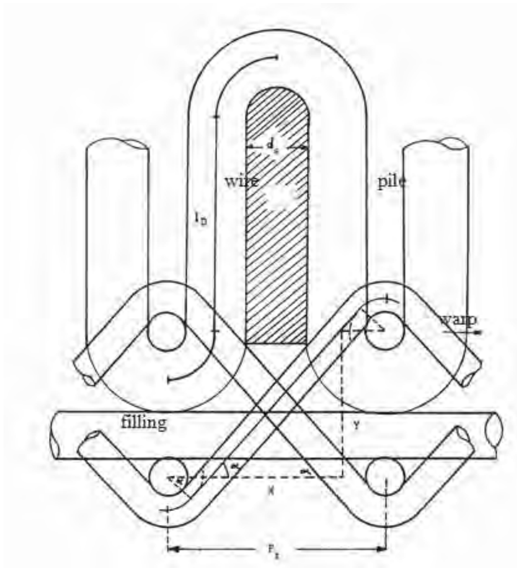

Figure 10. Double weft wire Wilton carpet structure at maximum pile density [19]

The unit lengths of yarns can be calculated from this theoretical model as follows:
If the thickness of the wire is denoted by d_s, its height by h_s and the length of the straight portion of the pile yarn by ℓ_D, then the unit length of the pile yarn may be expressed by

$$\ell_i = \frac{\pi}{2}(d_a + kd_i) + \frac{\pi}{2}(kd_i + d_s) + 2\ell_D \qquad (15)$$

Here d_a, d_i are diameters of the weft and pile yarns respectively and k is a flattenning coefficient for the pile yarn. Then, the unit length of the weave repeat, p_t, of the carpet of maximum set will be

$$p_t = d_a + 2kd_i + d_s \qquad (16)$$

If this length in the real carpet structure as shown in Figure 11 is denoted by p_i, the unit length of the pile yarn, ℓ_{ig}, will be given by

$$\ell_{ig} = \frac{\pi}{2} p_t + 2\sqrt{\ell_D^{\,2} + (p_i - p_t)^2 / 4} \qquad (17)$$

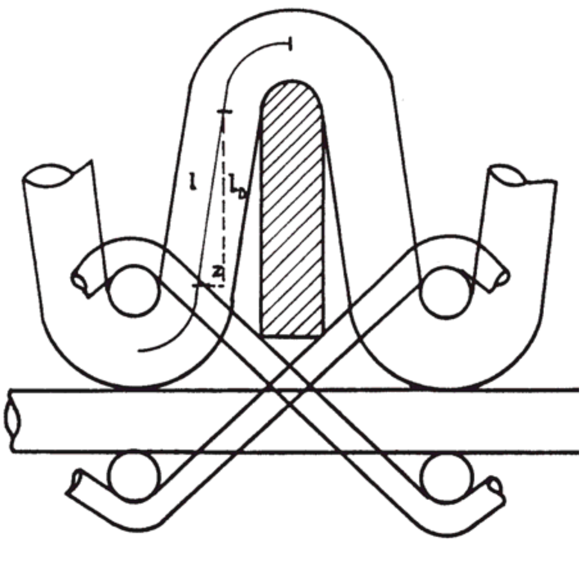

Figure 11. Double weft wire Wilton carpet structure in a certain pile density [19]

If the height of the carpet in weaving (measured from the carpet back to pile top) is H, then the straight length of the pile yarn will be

$$\ell_D = H - (kd_i + \frac{d_s}{2}) - (\frac{3}{2} d_a + kd_i + d_D + d_c) \qquad (18)$$

where d_c is the diameter of warp yarn.

From Figures 11 and 12, the height H will be found as

$$H = h_1 + h_2 + d_c \operatorname{cosec} 2\alpha \sin\alpha + d_a/2 + d_c + h_s + kd_i \qquad (19)$$

If, from Figure 12,

$$h_1 + h_2 = \frac{X}{2}\tan\alpha + \frac{d_s}{2}\tan\alpha$$

is substituted in equation (19) we obtain the height of the carpet during weaving as

$$H = \frac{1}{2}(X + d_s)\tan\alpha + d_c(1 + \operatorname{cosec} 2\alpha \sin\alpha) + d_a/2 + h_s + kd_i \qquad (20)$$

The unit lengths of the warp yarns, λ_c, for both the real carpet or the theoretical model which provides maximum pile density, will be expressed by the equation

$$\lambda_c = \frac{\pi}{2}(d_a + d_c) + \sqrt{X^2 + Y^2} \qquad (21)$$

Here the lengths X and Y will be given from Figure 10 by the equations

$$X = p - (d_a + d_c)\operatorname{cosec}\alpha \qquad (22)$$

$$Y = d_a + d_D + kd_i \qquad (23)$$

The slope angle of the warp yarns will be calculated by solving the equation

$$\tan\alpha = \frac{Y}{X} = \frac{d_a + d_D + kd_i}{p - (d_a + d_c)\operatorname{cosec}\alpha} \qquad (24)$$

The parameter p in equations (22) and (24) will be substituted by p_t or p_i depending on the geometrical model considered. In the real carpet, however, the straight length of the pile yarn, ℓ_{Dg}, will be obtained from Figure 11 by the equation

$$\ell_{Dg} = \sqrt{\ell_D^{\,2} + z^2} = \sqrt{\ell_D^{\,2} + (p_i - p_t)^2} \qquad (25)$$

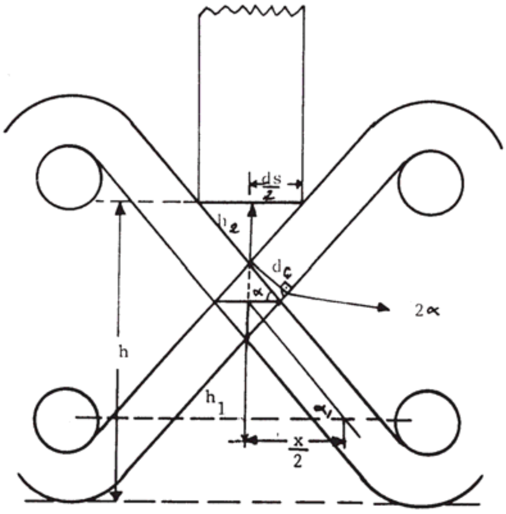

Figure 12. Determination of the level of the wire [19]

If an index of pile density $I = P_i / p_t$ is defined, then substituting $p_i = Ip_t$ in equations (17), (21), (22), (23) and (24) the unit pile length λ_{ig} (as in a real carpet), the angle α and the unit warp length λ_c for any yarn structure can be calculated. If this index is considered as a quality parameter, then for a prescribed quality level the carpet may be designed by the application of the given formulae with given yarn parameters.

3.2 Geometry of A Self Stitched Double Woven Fabric with 2/2 Twill Weave on Face and Back

The cross sectional geometry of a double woven fabric with 2/2 twill weave on face and back with maximum warp and weft stitches, is diagramatically shown in Figure 13 for one unit structure. Here the weft yarn of the top (face) fabric makes an intersection with the third warp yarn of the bottom (back) fabric (B3) and returns back again to its normal level on the top fabric.

A computer program was prepared to achieve automatic drawing of the cross sectional diagram of this fabric on the computer screen to obtain a compact structure. In the development of the geometrical model the cross sectional shape of the yarns were arranged to be circular, elliptic or race-track and the shape of the yarn contours lying in the cross sectional plane were assumed to be like a sine wave. The compactness would be achieved by arranging maximum yarn density (set) and minimum fabric thicknes by changing certain parameters like *t*, *h*, *f*, *c*, *e* and *z* shown in Figure 13, denoting fabric thickness, distance between fabric layers, length of flat part, space between yarn sections, sine curve amplitude and lateral displacement of layers respectively.

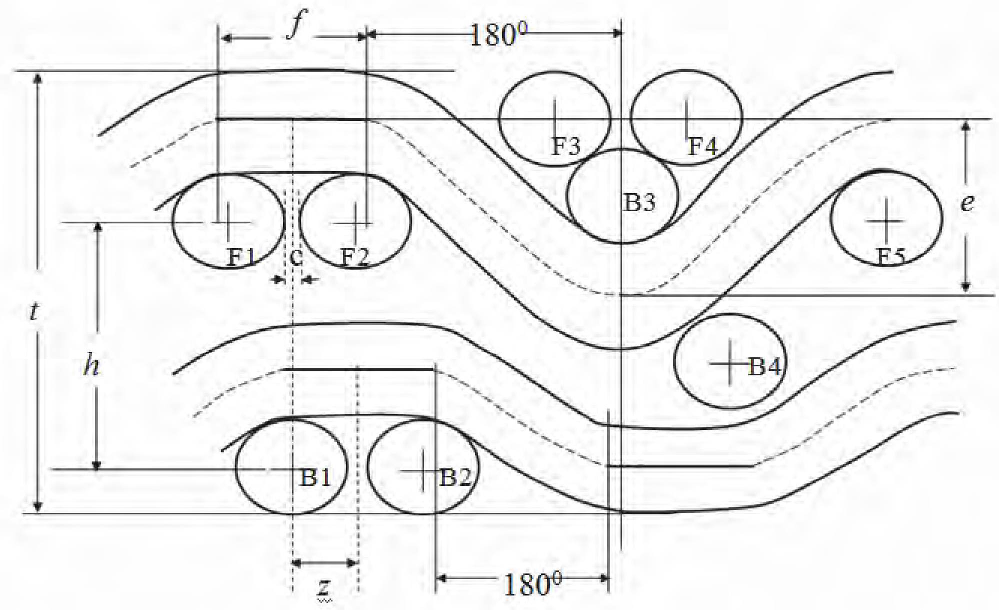

Figure 13. A cross sectional diagram of a self stitched double woven fabric with 2/2 twill weave on face and back with a weft stitch [20].

The program was also modified to move the third warp yarn of the bottom fabric (B3) up and down and the fourth warp yarn (B4) sideways by pressing certain letters on key board as inspired by visual inspection to obtain tangency with the nighbouring yarns.

3.2.1. Description of the Yarn Path in the Fabric Cross-sectional Plane

The yarn lying in the cross sectional plane is ssumed to be a sinus curve because of its resemblance to the elastica curve, which is the actual yarn shape in wowen structures, and because it is easy to express and manipulate mathematically. A sinus curve is drawn, first, as the central yarn axis, and then two other curves are drawn over and under this curve at a fixed distance away from it, to represent the surface outlines of the bent yarn, as shown in Figure 14. This fixed distance is the yarn radius *r*.

The yarn axis as the central sinus curve is expressed by

$$y = \sin x \tag{26}$$

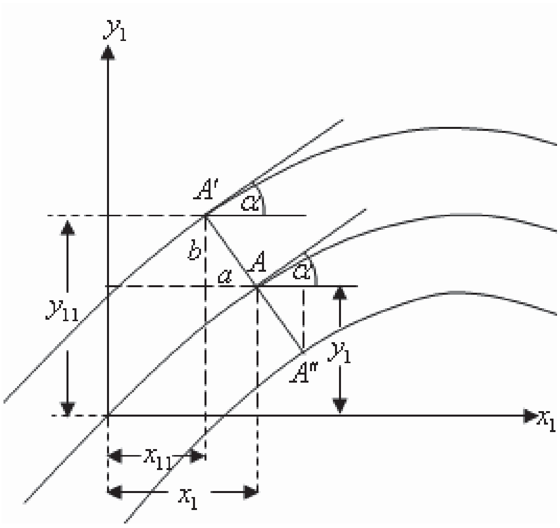

Figure 14. Description of yarn central axis and surface contour in the cross sectional plane

In real fabrics the distance between two weft yarns, p_1, which is half the period, can be expressed as

$$p_1 = c\pi \tag{27}$$

where *c* is a constant. The amplitude of the yarn curve, on the other hand, will be $h_1/2$, instead of 1 and assuming a square fabric construction where warp and weft yarns are of same type and count, this will be equal to yarn radius *r*. Thus the yarn path may be defined in terms of new coordinates x_1, y_1 as

$$x_1 = cx = \frac{p_1}{\pi}x \tag{28}$$

$$y_1 = \frac{h_1}{2}y = r\sin x \tag{29}$$

where *x* is in radians.

If a perpendicular is drawn to this curves at any point, the paralel curves will have tangents at the points of intersection with the perpendicular line, having the same slope expressed by

$$m = \frac{dy_1}{dx_1} = \frac{r\pi}{p_1}\cos x = \tan\alpha \tag{30}$$

The coordinates of the points on the outer curves corresponding to *A* can be given as

$$A^{'}(x_1 - a, y_1 + b) \tag{31}$$

$$A^{''}(x_1 + a, y_1 - b) \tag{32}$$

Consequently, from Figure 14, the coordinates of points $A^{'}$ and $A^{''}$ on the upper and lower curves can be written respectively by the equations

$$x_{11} = x_1 - a = \frac{p_1}{\pi}x - a\,,\; y_{11} = y_1 + b = \frac{h_1}{2}\sin x + b \tag{33}$$

$$x_{12} = x_1 - a = \frac{p_1}{\pi}x - a\,,\; y_{12} = y_1 + b = \frac{h_1}{2}\sin x + b \tag{34}$$

and furthermore,

$$\alpha = \arctan\left(\frac{r\pi}{p_1}\cos x\right) \tag{35}$$

$$a = r\sin\alpha \tag{36}$$

$$b = r\cos\alpha \tag{37}$$

Thus the yarn outlines are completely defined by equations (33) to (37) in terms of *x* which can be varied between 0 and 2π .

3.2.2. *Description of Yarn Cross-sectional Shape Outlines*

Yarn cross-sectional shaps around *z*- axis are either circular, elliptic or race-track, according to the theory used. Parametric equation of an ellipse given as

$$x = a\sin\theta \quad (38)$$

$$y = b\cos\theta \quad (39)$$

are used, where the major and minor diameters, *a* and *b* respectively, are to be calculated from a flattening coefficient $\varepsilon = a/b$. When $\varepsilon = 1$ a circle is obtained and a race-track section is described as a rectangle closed at two ends by two semi-circles.

3.2.3. *Computer Simulation*

The algorithm of the computer simulation programme, written in Q-basic language, was designed as based on the above described mathematical treatment. First the sinus curves are drawn, then, the yarn sections and straight portions are placed on appropriate places with respect to the sinus curve sections between the angles 0^o, 90^0, 270^0 and 450^0. The calculated parameters are written on the output page of the drawing together with the input parameters to numerically describe the designed fabric as shown in Figure 15, which is a theoretical example. The central line of the yarn binding with the cross yarn of the bottom fabric is also a sine curve with a greater amplitude to allow for binding without interaction of yarn surfaces by adjusting the parameter *e*.

3.2.4. *Experimental Work*

A more extensive research work was carried out later in the context of Soyheptemiz's M.Sc. thesis to investigate the validity of various assumptions in building up a double fabric geometry [23]. Two different wool/polyester blend worsted yarns were used to weave double cloth samples, one being a fine yarn of 52/2 Nm and the other being a much thicker yarn of 20/2 Nm count. 11 different double fabrics were woven on a 24 shaft dobby handloom. Small unit square weaves were used, namely 2/2 twill, 3/1 twill and 2/2 matt weaves. The two fabric layers were stitched together at appropriate stitching points, which would give perfect stitches. Twill and sateen stitching were applied as both warp and weft stitches and or as only warp or weft stitches.

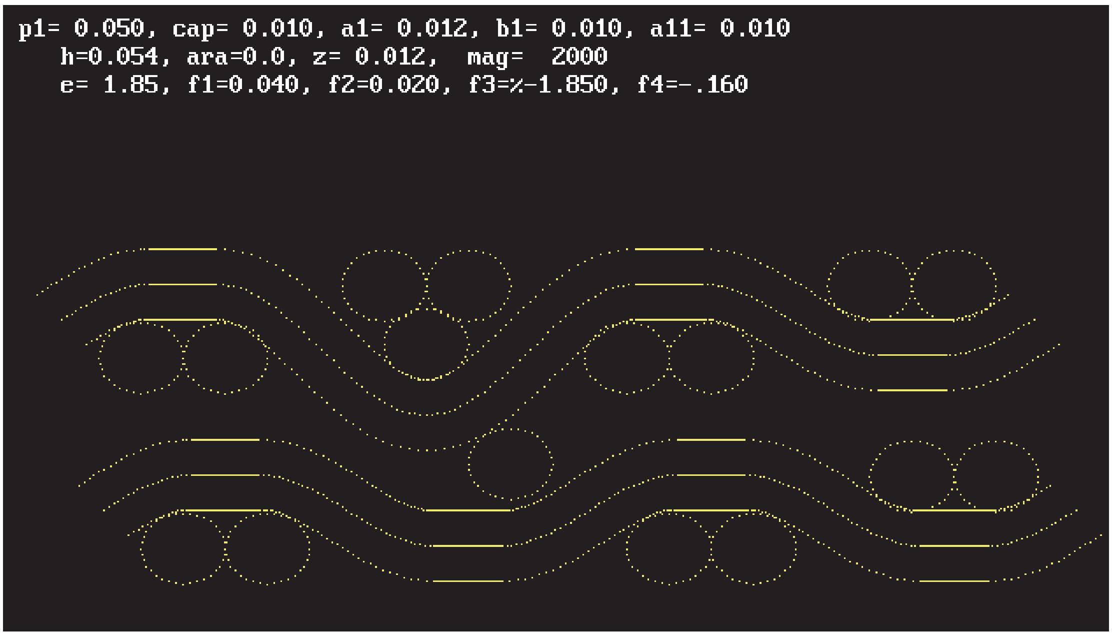

Figure 15. Computer simulation of the cross sectional diagram of a self stitched double fabric with 2/2 twill weave on both face and back as a theoretical example (original)

The main specifications of the experimental fabrics woven are given in Table 1 together with the codings used. The sets of the fabrics were determined using Ashenhurst's 1st setting theory, with appropriate reductions to allow for stitching. Reed counts were calculated assuming % 8 weaving and % 6 finishing contractions, and the available reeds of the nearest counts were selected for use. 8 heald shafts were used depending on weave types [24]. To simulate finishing process, grey fabrics were washed in 30^o water with a soap concentration of 5 gr/lt for 15 minutes. After washing they were relaxed to dry on a table for 24 hours and ironed. Then the fabrics were boiled in water and the same drying and ironing processes were repeated after.

The parameters determined on finished fabric samples are fabric thickness, yarn diameter measured both on yarns drawn from fabric and on that from the yarn bobbins, sample dimensions, fabric set, crimp factors and fabric weight. A projection microscope Projectina Heerbrugg was used to measure yarn diameter with 100 magnification. R&B Cloth Thicknes tester of James H. Heal was used to measure fabric thickness under 20, 30 and 40 g/cm^2 pressures and a presicion balance to measure sample weights [23]. The results are shown in Table 2.

A computer drawing program was prepeared using Visual Basic Studio package in which some parts of the fabric section were arranged to be moveable. The moving parts are used to obtain the best structure by searching the condition of the contacting yarn surfaces being tangent to each other, having smallest distance between intersecting yarn parts etc., thus giving a feasable fabric with normal sett and balanced binding at stitching points. In running the program the parameters like yarn flattenning coefficient and yarn porosity are given constant values. The first layer obtained is moved up and down to adjust the distance between top and bottom fabrics, the stitcing points are moved on both layers independently from each other, the bottom layer can be slid a distance with respect to the top one, the sinus curve sections at the stitching point expand vertically to gain greater amplitude. These movements are achieved by percentage changes on starting values of the related parameters given as imput successively.

A computational algorithm was added to the program to calculate yarn lengths to calculate crimp factors and fabric unit weigths of the simulated fabrics to provide for comparison with the measured values obtained on actual woven fabrics. Thus, if equation (28) and (29) are differentiated, we obtain

Table 1. Loom specifications

Yarn Count Nm	Loom Setting ends/cm	Reduction Factor	Reduced Loom Setting ends/cm	Reed Count Calculated	Reed Count Used	Weave Type	Stitch Type	Code
		0,76	37	90/4	90/4	2/2 twill	Twill warp & weft	211
						2/2 matt	Sateen warp & weft	243
						2/2 twill	Twill warp	212
						3/1 twill	Twill warp	222
		0,82	39,9	100/4	100/4	2/2 twill +2/2 matt	Sateen warp & weft	253
52/2	48,6	0,88	42,8	115/4	115/4	2/2 matt	Sateen warp	244
		0,82	24,7	60/4	115/2	2/2 twill	Twill warp & weft	111
						2/2 matt	Sateen warp & weft	143
						2/2 twill	Twill warp	112
						3/1 twill	Twill warp	122
20/2	38,1	0,88	26,5	65/4	60/4	2/2 twill +2/2 matt	Sateen warp & weft	153

Table 2. Fabric parameters determined on experimental fabrics [23]

Code	111	112	153	143	122	211	243	212	253	244	222
Measured Weft Setting (1/cm)	19,6	19,6	17,6	22,7	20,5	29,4	28	25,6	33,4	28,8	26
Measured Warp Setting (1/cm)	24,4	27,3	26,6	26,3	26,3	38,4	42	41,8	35,4	48,4	40,9
Weave Repeat Size (weft)(cm)	0,408	0,408	0,455	0,352	0,390	0,278	0,286	0,313	0,240	0,278	0,308
Weave Repeat Size (warp)(cm)	0,328	0,293	0,301	0,301	0,304	0,208	0,191	0,191	0,226	0,166	0,196
Weft Crimp Factor	1,071	1,089	1,086	1,126	1,089	1,016	1,051	1,031	1,064	1,031	1,040
Warp Crimp Factor	1,204	1,174	1,192	1,135	1,195	1,067	1,203	1,133	1,136	1,113	1,131
Fabric thickness (40 g/cm2)	1,454	1,676	1,976	1,776	1,734	1,454	1,09	1	1,06	1,164	1,114
Fabric thickness (30 g/cm2)	1,53	1,74	1,836	1,826	1,851	1,53	1,145	1	1	1,214	1,184
Fabric thickness (20 g/cm2)	1,598	1,846	1,876	1,896	1,966	1,598	1,216	1	1,15	1,244	1,244
Free Yarn Diameter (cm)	0,042	0,042	0,042	0,042	0,042	0,025	0,025	0,025	0,025	0,025	0,025
Weft Yarn Diameter in Fabric (cm)	0,041	0,042	0,038	0,041	0,040	0,021	0,023	0,023	0,233	0,023	0,022
Warp Yarn Diameter in Fabric (cm)	0,041	0,041	0,038	0,040	0,040	0,021	0,021	0,021	0,021	0,022	0,021
Fabric Unit Weight (g/cm2)	514	543	514	544,6	538	282	296	284,3	305,4	320	281

$$dx_1 = \frac{p_1}{\pi} dx \tag{40}$$

$$dy_1 = r \cos x dx \tag{41}$$

$$ds_1 = \sqrt{(dx)^2 + (dy)^2} = \left(\frac{p_1^{\ 2} + \pi^2 r^2}{\pi^2} \right)^{1/2} \left(1 - k^2 \sin^2 x\right)^{1/2} dx \ , \qquad k = \frac{\pi r}{\sqrt{p_1^{\ 2} + \pi^2 r^2}} \tag{42}$$

If equation (42) is integrated in the interval of $0 \le x \le \pi/2$, the arc length of one quarter of the sine wave will given by

$$s = \left(\frac{p_1^{\ 2} + \pi^2 r^2}{r^2} \right)^{1/2} \int_0^{\pi/2} \sqrt{1 - k^2 \sin^2 x}.dx \tag{43}$$

which can be expressed in terms of the comlete elliptic integral of the second kind $E(k, \pi/2)$.

3.2.5. Results

Statistical analyses for the correlation between the actual and theoretical values of crimp factor and fabric thickness show that at % 95 confidence limits, the correlation coefficients are important for crimp factors calculated by employing Ashenhurst's yarn diameter formula with circular and race track section, and also by applying Grosberg's yarn diameter formula with race track and elliptic sections, excepting 3/1 twill fabric. At % 95 confidence limits, the correlation coeffecients are important for thickness in respect to both all yarn cross sectional shapes and diameter formulae. The results of the statistical analyses are shown in Table 3 for various yarn cross sectional shape assumptions and yarn diameter calculation methods.

By a comparison of the parameters measured on sample fabrics and those given by the computer as fabric crimp and fabric thickness values, it can be concluded that the general approach to develop a double fabric geometry and modelling of different weaves are quite satisfactory. The experiments show that fabric thickness are greater in actual fabrics than calculated values. The most realistic simulation results have been obtained with the eliptic and race-track sections. As for the correlation between the measured and calculated unit fabric weight values correlation coefficients between 0.98 and 0.99 were obtained.

Table 3. Correlation coefficients between theoretical and experimental fabric parameters [23]

Structural parameter		Weft crimp factor	Warp crimp factor	Fabric thickness (cm)	
Yarn cross Section	Diameter formula			10 g/cm^2 pressure	20 g/cm^2 pressure
Ellips	Ashenhurst	0.58	0.13	0.84	0.73
	Grosberg	0.81	0.41	0.73	0.66
Race-track	Ashenhurst	0.67	0.24	0.87	0.77
	Grosberg	0.63	-0.03	0.71	0.64

Note: Critical correlation coefficient for % 95 confidence interval: r = 0.602

As a general evaluation of the results it can be stated that an adequate agreement could not be obtained between measured and calculated values for the warp crimp factor, but, however, better results were obtained with the elliptic yarn cross section assumption and applying Grosberg (Hearle, Grosberg, Backer)'s yarn diameter formula [5].

From the work carried out by Soyheptemiz, it can be concluded that any weave type of woven double fabric with any method of stitching can be modelled by the proposed computer simulation method provided that yarn counts are known [23].

3.3. Development of The Geometry of Complex Knitted Rib Structures from The 1x1 Rib Fabric Model

Examining curling tendency of plain knitted fabrics on the sides, Kurbak and Ekmen argued that the yarn bending to form a loop had a tendency to become straight which was prevented by the neighbouring loop while this caused fabric to bend at right angles to fabric plane at the sides since there was no attached loop. To model this state of fabric they adopted Kurbak (1998)'s plain knit loop model but cut the projection curve of the loop on a plane perpendicular to fabric plane in an appropriate way as shown in Figure 16 to obtain a new geometrical model [15, 25].

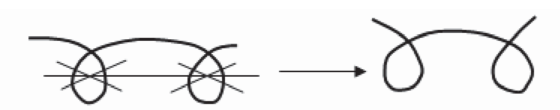

Figure 16. Geometric modelling of side curling of plain knitted fabrics [24]

Kurbak and Soydan adopted this model to develop geometric models of *mxm* rib fabrics, by considering a *mxm* rib structure as *m* plain loops followed by a 1x1 rib structure curled forwards and *m* plain loops followed by the same structure curled backwards with respect to fabric plane, following these steps [26]:

1. Fist a normal firmness degree such as l/d =20.19 is taken, where *l* il the loop length, *d* is the yarn diameter.

2. An α angle for each *mxm* rib structure as shown in Figure 17 is calculated from fabric photographs.

3. Those φ^* values satisfying α values given in Table 4 are calculated using a computer program written by Kurbak and Ekmen [25]. The angle φ^* is used to define the parametric ellips defining the shape of loop head as shown in Figure 18. The 2x2, 3x3, 4x4 ve 5x5 versions of rib structures are shown in Figure 19.

Figure 17. Determination of angle α [26]

4. The differences between left and right sections in *mxm* structures observed in Figure 18 are taken into account to estimate the parameters *t* and *v*. Here *t* is the fabric thickness, *w* is the wale spacing and *v* is a parameter related to wale spacing and yarn diameter $(v = -(w/2 - 2d)$.

5. This additional assumption will be made to define the jamming state between face and back loops: On the right side of the structure shown in Figure 19, the face part of the last plain loop at the back should be parallel to the face of the first loop in front. Likewise, on the left side of the structure, the face of the last plain loop in front should be parallel to the face part of the first plain loop at the back. This condition is shown in Figure 19 by parallel lines.

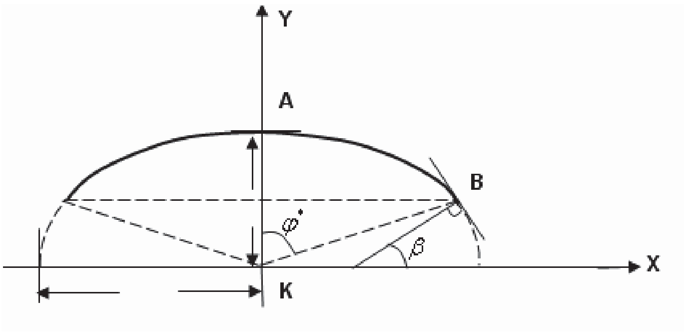

Figure 18. Modeling of the loop head [25]

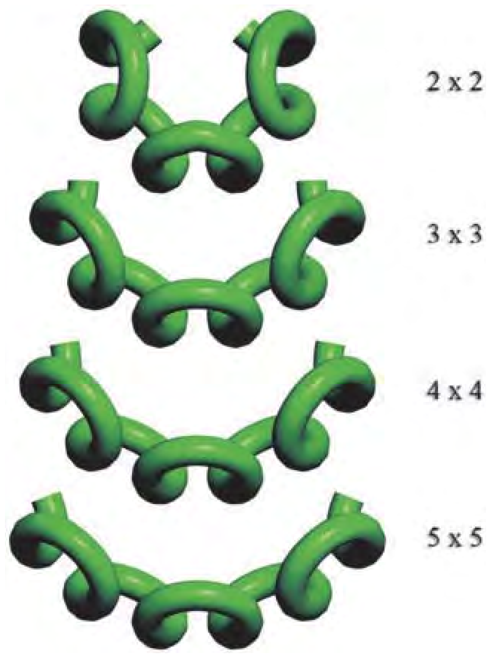

Figure 19. Definition of the angle for various *mxm* structures [26]

6. Parts of the first and last plain loops of the curled fabric sections are cut off and replaced by 1x1 rib units. In this fashion the shape of the loop heads of the first and last plain loops is changed and the 1x1 rib unit is placed as the curve B'ABCDE.

7. For the curve B'AB parametric ellipse model is applied and this section of the loop is defined as making the same angle as that loop removed.

Kurbak ve Soydan obtained the computer simulations of arious mxm rib structures by using computer programs they developed based on mathematical analyses on the abovementioned principles. Computer simulations of 2x2, 3x3, 4x4 rib weave structures are given in Figure 22 [26].

Table 4. Parameters estimated from fabric photographs [26]

Structure	Loop arm	t	v	φ^*	α
2x2	Left Right	1.29d 1.29d	0 +w/2=5.8/2d	86.04^0	90^0
3x3	Left Right	2d 2d	-w/2=-5.8/2d 0	87.41^0	60^0
4x4	Left Right	2.2d 2.2d	-w/2=-5.8/2d -w/4=-5.8/4d	87.75^0	52.5^0
5x5	Left Right	2.8d 2.8d	-w/2=-5.8/2d -w/2=-5.8/2d	88.10^0	45^0

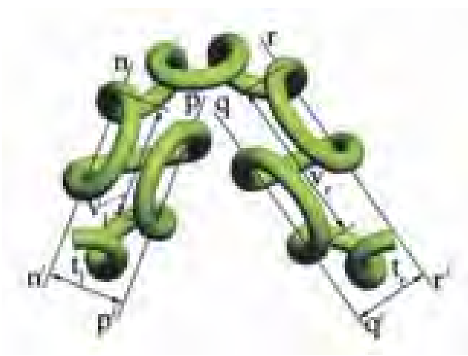

Figure 20. State of jamming of plain section with1x1 rib unit [26]

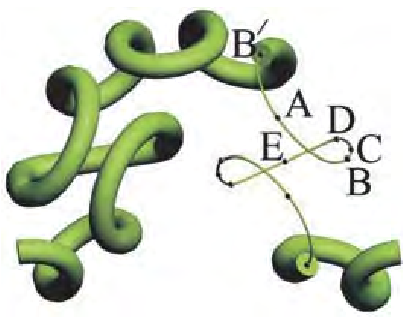

Figure 21. Formation of *mxm* rib structural [26]

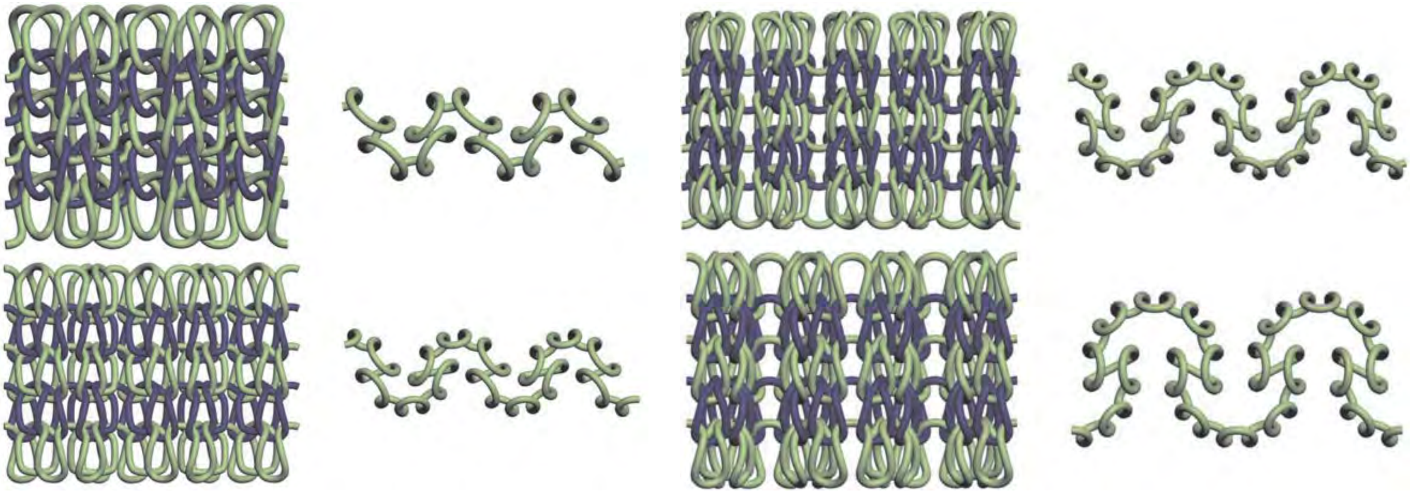

Figure 22. Computer simulations of *m*x*m* rib structures [26]

4. CONCLUSIONS

Product design practice involves defining the raw materials to be used and the structural parameters to be applied in the manufacture of the product. Computer provides a suitable medium to both carry out the necessary mathemetical calculations at great speed and also to simulate the appearance of the product to be viewed on screen. The three examples of complex fabric design described above display how computer can be used iteratively and flexibly to obtain the best design solutions to be monitored both by means of printed numerical results and graphical simulations.

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