NC STATE
Wilson College of Textiles

JTATM
Journal of Textile and Apparel, Technology and Management

Volume 11, Issue 4, 2020

Prediction of Areal Density of Embroidered Fabric and Analysis of the Influence of Embroidery Parameters on the GSM by Taguchi Method

Anirban Dutta, Biswapati Chatterjee,
Department of Textile Technology,
Government College of Engineering & Textile Technology,
India

ABSTRACT

With the rapid growth of the application of computerized embroidery in present apparel and fashion industry, it is important to have a prediction model for estimating the change in physical properties of fabric due to embroidery in the design and planning stage. In this context, a prediction model for the assessment of areal densities. GSM of the embroidered fabric has been established by using the basic stitch geometry. The model is statistically verified by set of embroidery samples and it is found that it can predict with a high level of accuracy. Also, a study has been made through Taguchi experiment design to find the influence of basic embroidery parameters like GSM of the base fabrics, stitch density and linear density of the embroidery threads on the GSM of embroidered fabric.

Keywords: Computerized Embroidery, GSM of Embroidered Fabrics, Embroidery of Apparel Fabrics, Taguchi, Prediction Model, Embroidery Design

1.0 Introduction

Nowadays the embroidery on textile fabrics is done mostly in computer controlled embroidery machines. Such machines are specially engineered with multi-needle fixed 'embroidery head' and a frame holder that moves the framed fabric in either of two mutually perpendicular directions so that the embroidery design can be sewn. The frame holder is known as a pantograph, which resembles a graph plotter, because it moves to the exact location (co-ordinates) of the design expressed in x and y values (Sugget G, 2010).

A study was made by Radaviciene S & Juciene M (Radaviciene S & Juciene M, 2012) to investigate the influence of embroidery threads on the accuracy of embroidery pattern dimensions. It was found that the higher linear density of embroidery threads results in a longer embroidery pattern & viscose embroidery threads are recommended as the nonconformity of the embroidery pattern dimensions. Also a thorough investigation had been reported in other papers of Radaviciene S & Juciene M (Radaviciene S & Juciene M, 2012) and also Radaviciene Set.al. (Radaviciene Set.al, 2013). It was found that different properties of the embroidery threads like linear density, bending rigidity etc. affects the formation of height and shape of the buckling waves of the base fabric inside of the embroidered element. Manal A. Seif et.al. (Seif Manal A,

2016) had investigated the effect of embroidery stitches on the properties of fabrics. Three types of embroidery stitches (Satin - Couching – Crossed back) in the form of longitudinal mid-area samples of cloth were carried out with two methods of embroidery formation, i.e. handmade and machine embroidery. Fabric properties like weight per unit area, thickness, bending stiffness, tensile strength and elongation were the properties under the study. Results were statistically analyzed and a comparison between results of the two methods were done to clarify the advantages and disadvantages of each method. It was found that the addition of embroidery threads increases the weight per unit area, thickness, bending stiffness and the elongation of the textile fabrics. Sukumar Nachiappan (Nachiappan S, 2009) investigated the effects of different types of seams like Plain seam, welt seam and French seam along with different stitch densities on the drape of fabrics. The effect of seams on the drape coefficient and drape profile had been studied. It had been reported that the drape coefficient significantly differs between the fabrics with different seam and also between the seam-stitch density combinations. Polyester/Viscose blended fabrics registered better drape profiles than that in case of Polyester/Cotton blended fabrics. In this context, the effects of seam parameters on the stiffness of woven fabric had been analyzed by Ayça Gurada (Gurada A, 2009). Also The effects of seam allowance and seam position on the drape behavior of plain and twill woven fabrics in terms of drape coefficient, node analysis and drape profile were investigated by Hu J and Chung S (Hu J & Chung S 1998).

It is noted that most of the previous research works are in the domain of the comparative study of the influence of different methods of embroidery process or types of embroidery threads on the behavior of embroidered fabrics. Also a number of research works have been made on the effect of seam and sewing threads on the properties of fabrics under sewing operation. Even though embroidery process is a combination of several stitches, there is a huge difference between sewing and embroidery process. Sewing mainly involves assembly of two fabric pieces, and hence stitches are mainly applied along the seam-line in linear locus. On the other hand the stitches in embroidery process are essentially applied along curvilinear locus depending upon the design unlike stitches in sewing run in linear locus along seam lines (Campbell E , 2014 , Suggett, G , 2013 , Oladipto , P.O.,2011 , Robert, S.D. , 2010). No specific prediction algorithm or mathematical relationship is available for estimation or prediction of the properties of embroidered fabrics.

In this context, an attempt has been made to develop a geometrical model of embroidered fabric and derive simple theoretical equation for estimation or prediction of the areal density i.e. GSM of embroidered fabrics. Also a detailed ANOVA study has been made using Taguchi method to determine the amount of influence of the each of the basic embroidery parameters on the GSM of embroidered fabrics.

2.0 Theoretical Considerations

In case of computerized embroidery machines, the mechanism of imparting the stitch is exactly like that in case of lockstitch formation in SNLS sewing machines (Campbell E , 2014 , Suggett, G , 2013). The path of embroidery thread in lockstitch can be assumed to be almost rectangular, as already established by profile projector (Rasheed, A. et.al, 2014). Here the threads are assumed to be incompressible of circular cross-section. The cross-sectional view of embroidered fabric with idealized geometry of interlocking between bobbin and needle thread is shown in figure 1.The notation used in this analysis are given below: denier of needle thread = D_1 , diameter of needle thread in mm = d_1 , denier of bobbin thread = D_2 , diameter of bobbin thread in mm = d_2 , the area of the design repeat = X (mm) x Y (mm) = A (sq. mm) , no of stitches per repeat = S, Stitch density in no of stitches per sq. cm = Q, stitch length in mm = L , base fabric thickness in mm = t , GSM of the base fabrics = G_B , total addition of weight in gram due to embroidery for the unit area of repeat size=W , b = linear distance between two consecutive stiches.

Thread consumption for one single stitch can be evaluated by the idealized geometry of fabric stitch system cross-section of which is shown in figure 1

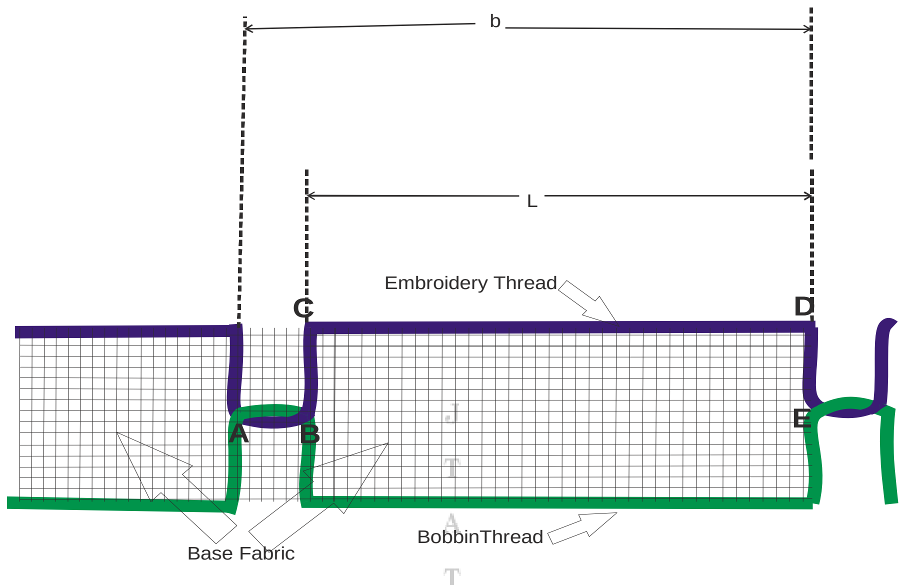

Figure 1: Geometry of one embroidery stitch in case of computerized embroidery

Length of embroidery thread consumed per one unit of stitch in mm= C_E

$$C_E = \text{Arc } AB + BC + CD + DE \quad (1)$$

Now, BC = DE = ½ x base fabric thickness = t/2, CD = Stitch Length = L

Length of Arc AB is calculated from geometry of the region of interlocking, in the Figure 2 which represents the cross-sectional view of region of interlocking between embroidery thread and bobbin thread.

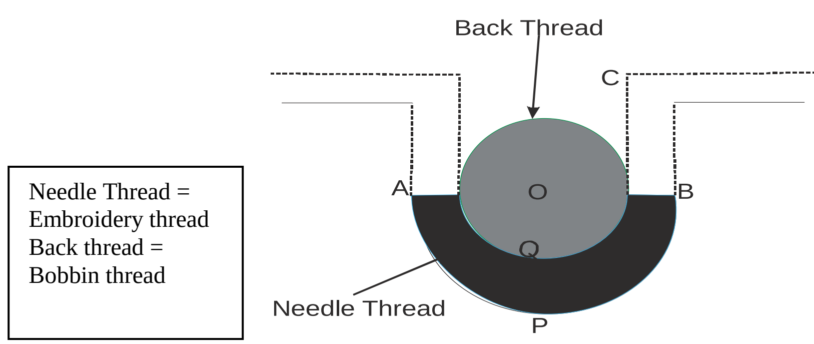

Figure 2: Geometrical representation of interlocking between Embroidery Thread and bobbin Thread

Radius of the Arc AB = OP = OQ + QP = Radius of Bobbin Thread + Diameter of the Needle Thread = $(½. d_2) + d_1$

Hence, Arc AB = $\pi. (d_2/2 + d_1)$ (2)

Therefore, we can rewrite the equation 1as:

$$C_E = \pi. (d_2/2 + d_1) + t/2 + l + t/2 \quad (3)$$

Now, using the relationship between linear density and the diameter of yarn in inch = 1/(28. $\sqrt{Ne}$) we obtain,

$$d_1 = 0.01244. \sqrt{D_1} \quad (4)$$

$$d_2 = 0.01244. \sqrt{D_2} \quad (5)$$

Replacing d_1 and d_2 in equation-1 by equation-4 and 5 the following equation can be obtained after simplification.

$$C_E = 0.0195.(2\sqrt{D_1} + \sqrt{D_2}) + l + t \quad (6)$$

Approaching the same way, the length of bobbin thread per unit stitch (C_B) in mm can be expressed as:

$$C_B = 0.0195.(2\sqrt{D_2} + \sqrt{D_1}) + l + t \quad (7)$$

Now, the total length of embroidery thread and bobbin thread are S x.C_N and S x C_B in mm respectively. The weight of the total length of embroidery threads (W_E) and bobbin threads (W_B) in gram per repeat of the embroidery design is as expressed below

$$W_E + W_B = (S.C_E .D_1).10^{-6}/9 + (S.C_B .D_2). 10^{-6}/9 \quad (8)$$

So, addition of weight due to embroidery per square meter of fabric (i.e. the increase of GSM) =

$$\Delta G = W_T. 10^6 / A \quad (9)$$

Therefore, the GSM of Embroidered fabrics (G_E) can be expressed as

$$G_E = G_B + \Delta G \quad (10)$$

Now, replacing ΔG, W_T, C_E and C_B by equation 9, 8, 7 and 6 respectively, and after necessary simplifications, it can be derived.

$$G_E = G_B + (S/9A).[0.0195.\{D_1.(2\sqrt{D_1}+\sqrt{D_2}) + D_2. (2\sqrt{D_2} + \sqrt{D_1})\} + (l + t). (D_1 + D_2)] \quad (11)$$

3.0 Materials and Methods

3.1 Plan of Material

3.1.1 Fabric

Three different Shirting-fabrics of plain weave structure, representing three different GSM values are selected as the base fabrics for the embroidery work. GSM values of the base fabrics are selected in such a way that it represents three different levels of the GSM of regular shirting fabrics. The average values of GSM and thickness of the fabrics procured are given in the Table 2.

3.1.2 Embroidery Thread

2-Ply Filament Embroidery thread of three different linear densities (in Denier) are selected for embroidery work. The technical details of the embroidery threads procured are given in the Table 2.

3.1.3 Embroidery Design Details

Three embroidery designs are selected in such a way so that three different levels of stitch density are well represented. Designs are made in embroidery CAD software of Tajima. The embroidery is done on 21-head computerized embroidery machine with the specification as 21 head X 9 needle X 300 mm head interval X 1000 max RPM. The design details are represented by the Table 1.

Table 1: Embroidery Design Details

Design Number	Repeat Area (X x Y) in mm	Total number of stitch per repeat	Stitch Density in no of Stitches/Sq cm	Image of one full repeat of the design
D-1	300 X 410	7340	5.97	
D-2	300 X 320	24209	25.22	
D-3	300 X 407	41103	33.67	

3.2 Design of Experiment

In order to produce different embroidered fabrics from varying parameters, the Taguchi L9orthogonal array experiment design method has been adopted in this study. Three input parameters are selected as 1) GSM of the base fabric 2) Denier of the embroidery thread and 3) Stitch density of the embroidery design, representing fabric parameter, thread parameter and design parameter respectively. That means total nine different combinations of input parameters, i.e. total 9 runs are planned with four observations for each of those, constituting a plan of total 36 different embroidered samples.

3.2.1 Selection of Levels of Input Parameters

Three levels (i.e. Low, Medium and High, as represented by 1, 2 1nd 3 respectively are considered for each of the three input parameters. The levels selected are as shown in the Table 2.

Table 2: Table for the Selection of Levels of Input Factors

Input parameter	Low(1)	Medium(2)	High(3)
GSM (rounded value) of the base fabric **[average thickness in mm]** (Plain woven P/C blended shirting fabric)	106 [0.163]	116 [0.193]	126 [0.236]
Denier of the embroidery thread (rounded value) (100% PET filament , 2 Ply , Z)	230	285	360
Stitch density of the embroidery design (average no of stiches per square cm)	5.97	25.22	33.66

3.2.2 The Response or the Output Parameter

The output parameter for the experiment matrix is planned as the GSM of the fabric after embroidery.

3.3 Experiment Design Matrix

The design matrix for the experiment is expressed in the Table 3.

Table 3: Experiment Design Matrix

Input parameter	Low (1)	Medium (2)	High (3)
GSM (rounded value) of the base fabric **[average thickness in mm]** (Plain woven P/C blended shirting fabric)	106 [0.163]	116 [0.193]	126 [0.236]
Denier of the embroidery thread (rounded value) (100% PET filament , 2 Ply , Z)	230	285	360
Stitch density of the embroidery design (average no of stiches per square cm)	5.97	25.22	33.66

Four samples are prepared in four different heads of the machine for each of the 9 runs shown in Table 3. The GSM of the fabric after embroidery is determined for each of the samples.

3.4 Testing Procedures

3.4.1 Testing of base fabric parameters

3.4.1.1 Testing of GSM of Base Fabric

While testing the GSM of base fabrics, total ten readings have been taken for each of the fabrics, using a template size of 10 X 10 cm in each of the cases. GSM is determined according to ASTM D3776 standards of measurement of fabric areal density.

3.4.1.2 Testing of Thickness of Base Fabric

Testing of Thickness of all the three base fabrics is done on DigiThick digital thickness tester, MAG Solvics, India as per ASTM-D1777 standards.

3.4.1.3 Testing of Denier of the Embroidery Threads

In case of the measurements of the Denier of embroidery threads, total ten readings have been taken for each of the embroidery threads. Denier measurement is done according to the standard procedure as per ASTM D1907

3.4.2 Testing of embroidery parameters

The stitch density and stitch length on the embroidered fabrics are not uniform and they widely vary from segment to segment within the same repeat of the design according to the nature of the designs. Therefore, embroidered fabrics are heterogeneous in nature so far as the areal density of fabric and other stitch properties are concerned. Keeping this into mind, it is obvious that traditional methods of testing of GSM and thickness of plain fabrics cannot be fully applicable in the present case of testing the embroidered fabrics. The following methods have been adopted for testing different properties of embroidered fabrics.

3.4.2.1 Testing of GSM of Embroidered Fabric

The following method has been adopted for testing the GSM of embroidered fabrics.

a) Dividing one repeat of the design into distinct segments according to the design distribution, in such a way that segments are distinctly separable from each other and set apart by a reasonable portion of the unembroidered portion.
b) Determination of GSM values for each of the identified segments and counting the number of occurrence of each of the identified segments (i.e. frequency of each segment in one repeat of the embroidery design).
c) Taking the weighted average of those values to obtain the GSM for the entire embroidered fabrics.

For example if there are n number of segments as $s_1, s_2, \ldots, s_n$, the GSM for each of the segments are to be determined denoting as g_1 , g_2 , ….. , g_n . Now, if frequencies of those segments are denoted as f_1 , f_2 , …. , f_n , the GSM of the entire fabric will be equal to $1/\sum(f_i) . \sum(g_i . f_i)$.

The above mentioned process is demonstrated through the design represented by figure 3. The entire repeat of the embroidery design is represented by the rectangle ABCD. This one full repeat is divided into two segments PQRS (indicated by Segment-1 in the figure) and ABFE (indicated by Segment-2 in the figure) in the figure 3, which are distinctly separable from each other and set apart by a reasonable amount of unembroidered portion. Among those two segments, the frequencies of segment-1 and segment-2 can be counted as 3 and 1 respectively, as shown in the figure 3. Therefore, in this case if the GSM values of segment-1 and segment-2 are α and β respectively, then the average GSM for the entire embroidered fabric can be expressed as ¼. (3.α + β).

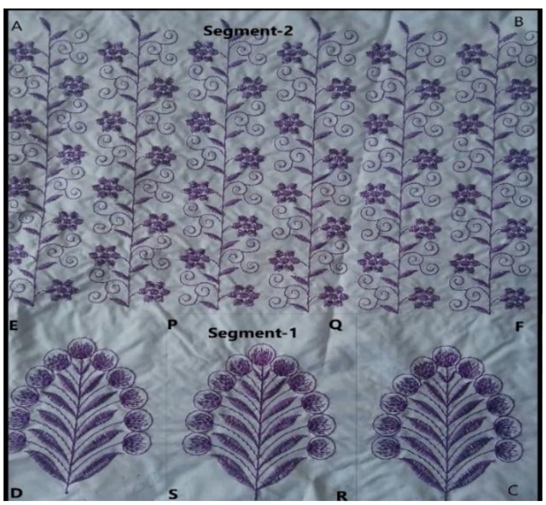

Figure 3: Division of one full design into segments

3.4.2.2 Determination of the Average Stitch Length of the Embroidered Samples

Unlike in case of sewing, In the case of embroidery, there is no fixed stitch length for a particular design. Since the stitch length varies according to the design pattern. Therefore, there are a multiple values of stitch lengths with corresponding frequency values in case of embroidery design. Hence, the weighted average method has been adopted in this case to calculate the average stitch length for each of the designs. The following formula is used to determine average stitch length for a particular embroidery design.

Average Stitch length (L)= $1/N. (\sum l_i.f_i)$ (12)

Where, l_i = i^{th} value of stitch length, f_i = frequency of occurrence of the i^{th} value of stitch length, N = total number of stitch per repeat = $\sum f_{i.}$

The principle adopted in this paper for determining the average stitch length of one full repeat of the embroidery design is illustrated through the design represented by figure 4. The Design ABCD in figure 4 has multiple segments like leaves (L1, L1'), Flower (F1), main stem (T) and branch stem (V). Each of the segments consists of multiple stiches of variable stitch lengths. For example, each of the two identical big leaves L1 & L1' have the stich length distribution measured as 2 mm X 4 stitches , 3 mm X 5 stitches , 4 mm X 7 stitches and 5 mm X 16 stitches . Similarly, stitch distribution for each of the smaller leaves, each of the 11 Flowers (F1), each of the 10 side-branches (V) and the main stem (T) are determined with the help of calibrated millimeter scale and a magnifying glass.

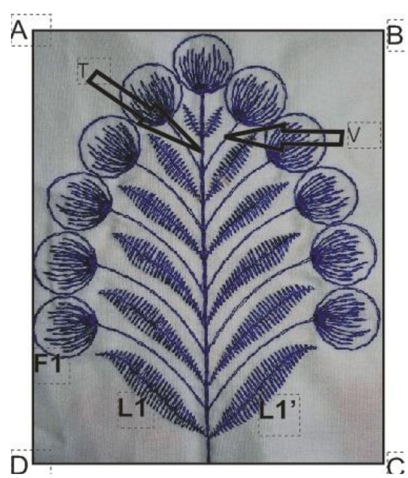

Figure 4: Embroidery Motif

Combining all the stitches of the entire repeat ABCD of figure 4, the curve represented by figure 5 and the Table 4 can be prepared to represent the frequency distribution of stitch length values of the design repeat ABCD and determine the average stitch length of the entire design. This principle can be adopted for any repeat size of the embroidery design. Even though this process appears to be tedious, but it can be automatized with the help of digital scanner and image analysis software.

Table 4: Frequency Distribution Table for Stitch Length

Stitch length (mm)	Total Frequency	Average Stitch Length (mm)
1	20	3.02
2	44	
3	1030	
4	56	
5	128	

4.0 Result Analysis

All the results obtained from the experiments are given in table 5.

4.1 Analysis of Significance of the Input Parameters

The contribution or significances of each of the three input parameters are calculated through the Signal to Noise ratio (S/N) and ANOVA analysis from the Taguchi Orthogonal Array. The Results as obtained for all the 9 runs are represented by the following table.

It is obvious that for the apparel fabrics, the GSM of the fabrics must be within a typical range so far as the drapability and comfort of the fabric are concerned. Hence it is desirable that the GSM of the fabric after embroidery should remain either as minimum as possible or close to a target value specified by the garment designer. Keeping these two considerations in mind, the following two approaches of the output value have been adopted here: a) Lower is better, i.e. lower is the value of GSM after embroidery, better is the acceptability so far as the end-use requirements are concerned. b) Target is the best, i.e. closer the value of GSM after embroidery to a predetermined target value, better is the acceptability. Detailed step by step analysis has been made for the Signal to Noise ratio (S/N) relationships and ANOVA for the two categories of approaches as mentioned above.

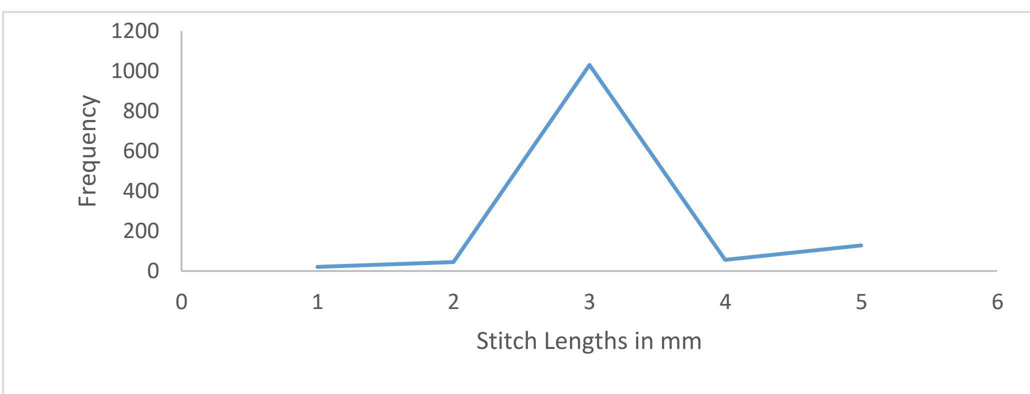

Figure 5: Frequency Distribution Curve for Stitch Length

Table 5: Experimental Results for GSM of the embroidered fabric according to Taguchi experiment design.

Run No.	Input parameters with actual Value			GSM of the embroidered fabrics			
	Fabric GSM	Needle thread Denier	Stitch Density	Sample-1	Sample-2	Sample-3	Sample-4
1	106	235	5.97	125.08	123.25	127.43	125.26
2	106	285	25.22	153.62	151.78	153.05	152.96
3	106	360	33.66	179.63	188.39	183.10	183.97
4	116	235	25.22	161.39	165.81	159.97	162.41
5	116	285	33.66	191.07	187.33	193.83	190.88
6	116	360	5.97	139.14	129.93	144.47	137.92
7	126	235	33.66	184.99	183.73	186.82	184.97
8	126	285	5.97	144.24	138.36	139.80	140.99
9	126	360	25.22	186.88	189.61	186.55	187.63

Table 6: ANOVA analysis for 'Lower is better' approach

Source of variation	DOF	Sum of squares	Mean square	Computed F	% of total variation represented
GSM of base fab	2	1.38	0.69	5.70	9.31
Denier of embroidery thread	2	0.70	0.35	2.90	4.74
Stitch density	2	12.52	6.26	51.61	84.32
Error	2	0.24	0.12		

4.1.1 Result Analysis for the Category 'Lower is Better'

The detailed step-by step analysis for the calculation of S/N values and significances of each of the input parameters in this category are represented by Table 6. It is observed that out of all the three input parameters selected in this study, the parameter stitch density of the embroidery design shows the highest significance, whereas the remaining two parameters i.e. GSM of the base fabric and the linear density of embroidery thread show much less significance, so far as the GSM of embroidered fabric is concerned. Therefore, it is evident that the stitch density is appeared to be the most influential input parameter for the GSM after embroidery.

Also the S/N Curves have been plotted to display the relationship between the values of the input parameters and the robustness i.e. the resistance to uncontrolled variations are concerned. All those S/N curves are represented by the figure 6 to 8.

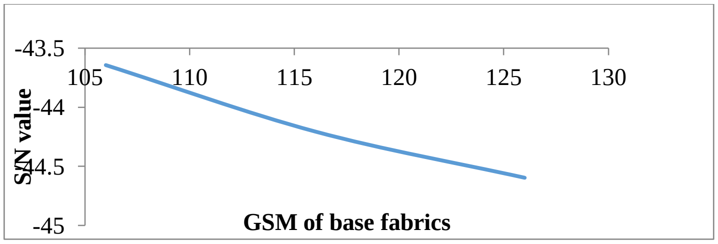

Figure 6: GSM of base fabrics vs S/N values in case of 'Lower is better approach'

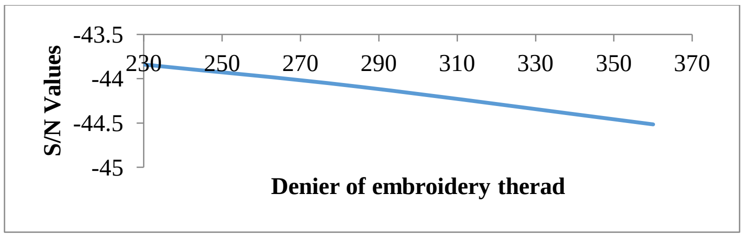

Figure 7: Denier of embroidery thread vs S/N in case of 'Lower is better approach'

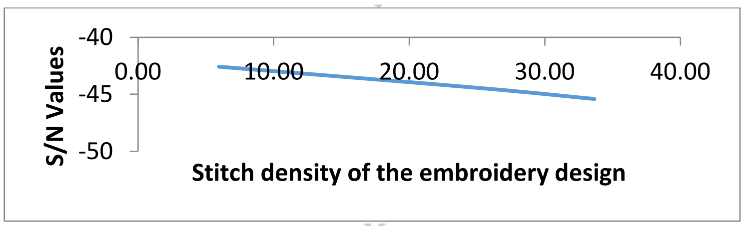

Figure 8: Stitch Density of embroidery vs S/N in case of 'Lower is better approach'

Since the signal-to-noise ratio (S/N) represents the robustness of the experiment against the noise factors. Hence, higher the uncontrollable external factors in the system. value of S/N, higher is the resistance of the system against the variations due to noise or uncontrollable external factors in the system.

It is observed in figure 6 that S/N decreases steadily as the GSM of the base fabric increases. Which means the higher GSM values of base fabrics degrades the robustness of the system. This causes the system to be more vulnerable to external variations. Same trend is observed in case of other two input parameters i.e. Denier of embroidery thread and the stitch density of the embroidery design as it is evident from the figure 7 and 8 respectively.

Therefore, it is found that in this context, the robustness of the system deteriorates at the higher values of the process parameters. It can be explained by the fact that higher GSM value of base fabrics corresponds to the higher thickness of the base fabrics and also higher warp and weft densities. As the thickness of fabric increases, the path of the embroidery thread inside the fabric structure is also increased. In addition to that, due to the higher densities of warp and weft yarns, the penetration of embroidery yarns into the fabric structure is subject to more resistance. These factors are responsible for increase of the probability of variations i.e. noise in the system. In the similar manner, the coarser embroidery threads result in more noise in the system, which in turn reduces the S/N value. Finally, S/N value linearly decreases with the increase of stitch density as well. That means higher the density of the embroidery stitch, lower is the resistance of the system against the variations due to noise.

4.1.2 Result Analysis for the Category 'Target is the Best'

In case of 'Target is better' approach the formulae for calculating the S/N value is as given below.

$$(S/N)_{i \text{ for 'target is best'}} = 10.\log_{10}(T^2/ S_T^2) \quad (13)$$

Where, T = Target Value, S_T = Standard Deviation of i^{th} run with respect to the target response value.

The similar sequence of steps has been followed as shown in 4.1.1 for the result analysis in this case. Analysis is done in three different segments, keeping the target value for the GSM of the embroidered fabrics as120, 135 and 150. The statistical analysis and the graphical representations of the relationships between Signal to Noise ratio and input parameters are represented by Table 7 and the figure number 9-11 respectively.

Table 7: ANOVA for 'Target is the Best' Approach

Source of variation	DOF	Target is set at 120			Target is set at 135			Target is set at 150		
		Sum of squares	Mean square	Computed F	Sum of squares	Mean square	Computed F	Sum of squares	Mean square	Computed F
GSM of base fab	2	1.48	0.74	5.81	1.58	0.79	5.93	1.58	0.79	5.93
Denier of embroidery thread	2	0.75	0.38	2.96	0.80	0.40	3.02	0.80	0.40	3.02
Stitch density	2	13.36	6.68	52.57	14.29	7.15	53.62	14.29	7.15	53.62
Error	2	0.25	0.13		0.27	0.13		0.27	0.13	

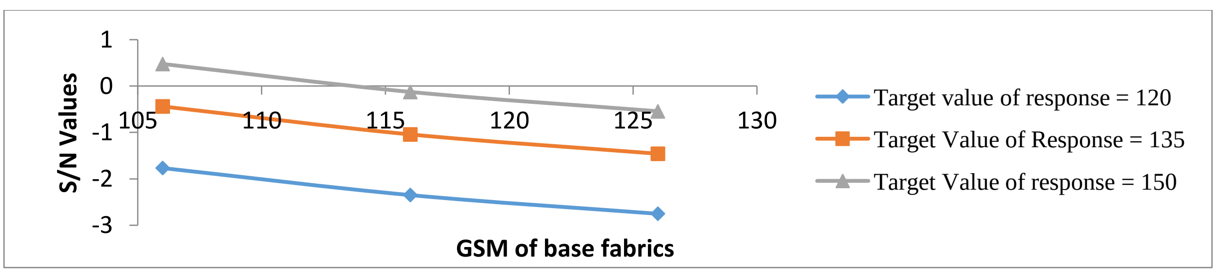

Figure 9: GSM of base fab vs S/N in case of 'target is the best' approach

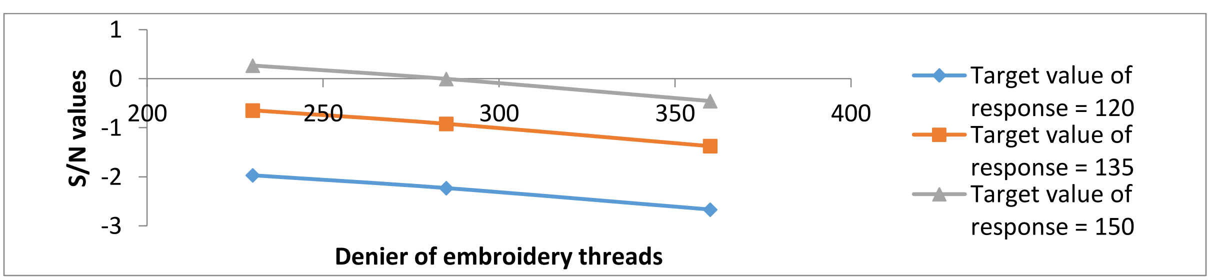

Figure 10: Denier of embroidery thread vs S/N in case of 'target is the best' approach.

Table 8: Predicted and actual GSM values of the embroidered samples

sl no	Base-fabric GSM	Needle thread Denier	Stitch Density (No of Stitches per square cm)	Fabric Thickness in mm	Average Stitch Length in mm	Predicted GSM of embroidered fab (y) as per eq 11	Actual GSM of embroidered Fabric	Coeff of correlation between Actual GSM and Predicted GSM
1	106	230	5.97	0.16	5.44	124.42	125.08	**0.96**
2	106	230	5.97	0.16	5.44	124.42	123.25	
3	106	230	5.97	0.16	5.44	124.42	127.43	
4	106	230	5.97	0.16	5.44	124.42	125.26	
5	106	285	25.22	0.16	2.65	156.61	153.62	
6	106	285	25.22	0.16	2.65	156.61	151.78	
7	106	285	25.22	0.16	2.65	156.61	153.05	
8	106	285	25.22	0.16	2.65	156.61	152.96	
9	106	360	33.66	0.16	3.50	203.30	179.63	
10	106	360	33.66	0.16	3.50	203.30	188.39	
11	106	360	33.66	0.16	3.50	203.30	183.10	
12	106	360	33.66	0.16	3.50	203.30	183.97	
13	116	230	25.22	0.19	2.65	160.58	161.39	
14	116	230	25.22	0.19	2.65	160.58	165.81	
15	116	230	25.22	0.19	2.65	160.58	159.97	
16	116	230	25.22	0.19	2.65	160.58	162.41	
17	116	285	33.66	0.19	3.50	199.54	191.07	
18	116	285	33.66	0.19	3.50	199.54	187.33	
19	116	285	33.66	0.19	3.50	199.54	193.83	
20	116	285	33.66	0.19	3.50	199.54	190.88	
21	116	360	5.97	0.19	5.44	140.56	139.14	
22	116	360	5.97	0.19	5.44	140.56	129.93	
23	116	360	5.97	0.19	5.44	140.56	144.47	
24	116	360	5.97	0.19	5.44	140.56	137.92	
25	126	230	33.66	0.24	3.50	199.89	184.99	
26	126	230	33.66	0.24	3.50	199.89	183.73	
27	126	230	33.66	0.24	3.50	199.89	186.82	
28	126	230	33.66	0.24	3.50	199.89	184.97	
29	126	285	5.97	0.24	5.44	147.18	144.24	
30	126	285	5.97	0.24	5.44	147.18	138.36	
31	126	285	5.97	0.24	5.44	147.18	139.80	
32	126	285	5.97	0.24	5.44	147.18	140.99	
33	126	360	25.22	0.24	2.65	186.68	186.88	
34	126	360	25.22	0.24	2.65	186.68	189.61	
35	126	360	25.22	0.24	2.65	186.68	186.55	
36	126	360	25.22	0.24	2.65	186.68	187.63	
37	126.200	295.000	25.220	0.236	2.65	179.00	184.57	
38	116.800	285.000	25.220	0.193	2.65	167.82	183.37	
39	126.200	275.000	25.220	0.236	2.649	176.61	178.51	
40	116.800	238.280	25.220	0.193	2.649	162.34	168.87	
41	116.800	360.000	25.220	0.193	2.649	176.81	176.05	
42	126.200	230.000	33.660	0.236	3.500	200.08	193.79	
43	126.200	360.000	5.97	0.236	5.440	150.92	148.74	

44	116.800	238.280	25.220	0.193	2.649	162.34	168.87
45	116.800	238.280	25.220	0.193	2.649	162.34	155.99
46	116.800	275.000	5.97	0.193	5.440	137.38	138.10
47	116.800	275.000	5.97	0.193	5.440	137.38	136.23
48	116.800	275.000	5.970	0.193	5.440	137.39	131.09
49	116.800	275.000	5.970	0.193	5.440	137.39	140.84
50	106.100	335.000	33.660	0.163	3.500	198.59	188.57

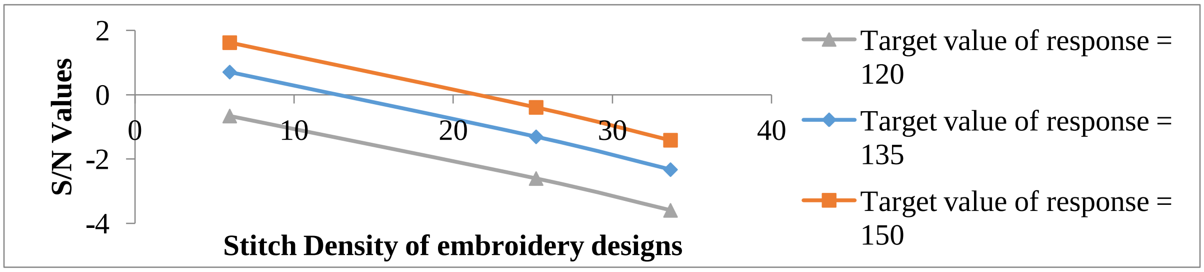

Figure 11: Stitch density of embroidery vs S/N in case of 'target is the best' approach

In this case also it is evident from the table 7 that the stitch density of the embroidery design is found to be the most significant parameter so far as GSM of embroidery fabric is concerned. And hence it can be stated that a certain control over the stitch density of the design at the planning stage can help in keeping the GSM after embroidery within a specified range as par the end-use requirements.

It is evident from the figure 9, 10 & 11 that the trend of relationships found between the input parameters and the S/N values are very similar to that in case of 'lower is better approach', represented in the 4.1.1. That means in this case also the robustness of the system deteriorates as the values of the process parameters are increased.

4.2 Validation of the Theoretical Prediction Model Developed for the GSM of Embroidered Fabrics

The total 36 samples as manufactured according to Taguchi Design of Experiment (refer. Table 5), and an additional 14 randomly prepared embroidery samples, i.e. a total 50 number of embroidered samples are used for verification of the theoretically developed prediction equation (Eq. 11) for predicting the GSM of the embroidered fabric. The results are represented by the table 8.

The Graphical representation of the comparative analysis between calculated and Actual values of the GSM of the embroidered fabric is represented by figure 12.

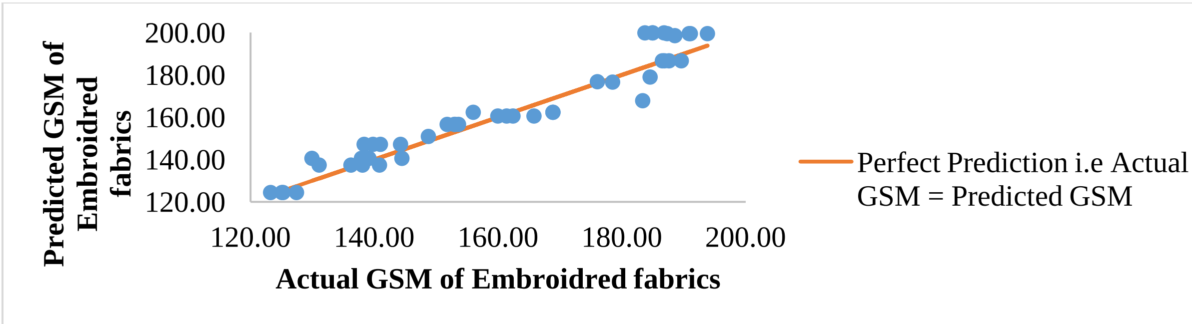

Figure 12: Actual and predicted GSM of embroidered fabric.

Table 9: F-test results for the theoretical prediction equation developed.

Attributes	Predicted GSM after Embroidery as per equation number 11 (G_E)	Actual GSM of Embroidered Fabric (G_E')
Mean	167.23	163.20
Variance	690.82	532.50
Observations	50	50
df	49	49
F	1.30	
F Critical one-tail	1.61	

In addition to the above analysis, F-test is done to check the 'goodness of fit' of the theoretical equation derived. The results of F-test thus obtained are represented by the table 9. It is evident that the F-value obtained in the analysis is less than the critical values of F at 95% confidence limit. And hence it can be stated that no statistically significant difference has been found between the actual value and predicted value of the GSM of embroidered fabric. Also a very satisfactory correlation of coefficient between predicted and actual values in this context is found (ref Table 8).

5.0 Summary and Conclusions

The homogeneous nature of plain woven textile fabrics is transformed into heterogeneous structure after embroidery so far as the areal density is concerned. Due to the non-uniformity of the stitch distribution on the fabric surface, the areal density of embroidered fabric varies from segment to segment. A method has been adopted here to measure the GSM of embroidered fabrics through weighted average technique. Also, unlike in the sewing process, since multiple stitch lengths are used in embroidery, an analytical method of determination of average stitch lengths of embroidered samples is adopted.

The experiment is planned based upon Taguchi design. A very significant increment in GSM of base fabrics due to embroidery process is observed mainly due to the addition of embroidery threads. It is observed that the stitch density of the embroidery design is emerged as the most influential input parameter so far as the GSM of embroidered fabric is concerned. Therefore, lower levels of stitch density and linear density of embroidery thread are desirable in order to keep the GSM of the embroidered fabric within a range suitable for apparel fabrics.

It is further perceived that the robustness of the process deteriorates at the higher levels of process parameters i.e. stitch density and linear density of the embroidery thread. But at the same time it must be kept into mind that higher stitch density of embroidery design is necessary to increase the fullness and aesthetic value of the designs. Clearly in this context a conflict is observed between two objectives i.e. keeping the GSM of embroidered fabric& noise level of the process at lower level and achieving the fullness of the design. Hence, further researches need to be carried out to determine the most desirable values of process parameters to optimize, i.e. satisfy both of the above mentioned objectives.

A prediction equation is theoretically derived from the geometry of embroidery stitches. The equation is verified and a very high level of prediction accuracy in terms of coefficient of correlation and the F-test have been found. This prediction model can help the embroidery designers or garment designers significantly to pre-estimate the GSM of the embroidered fabrics. Hence the designer can adjust the embroidery and thread parameters in the planning and designing stage itself to ensure that the GSM values of embroidered fabrics remain within desirable range, depending upon the end-use requirements of that fabric. In addition to that, this prediction equation can also enable the merchandisers to pre-assess the amount of thread consumption for a particular embroidery design.

References

Campbell, E (2014), "Stitch Types in Machine Embroidery and Digitizing': '*The Only Stitch'* , *October 2014, Retrieved from* http://www.mrxstitch.com/ghost-embroidery-machine-stitch-types-machine-embroidery-digitizing-stitch/

Gurada, A (2015) 'Effect of Seam Parameters on Stiffness of Woven Fabrics', Retrieved from https://www.google.co.in/url?sa=t&source=web&rct=j&url=http://dergipark.gov.tr/download/article-file/218102&ved=2ahUKEwjGw7e74bfbAhUHT48KHTULBvIQFjAAegQIBRAB&usg=AOvVaw3pgmoggfMtv2UKMcXbVch2

Henry, D. (2006) 'Stitch Perfect: The Best Machine Embroidery Thread', Retrieved from https://www.craftsy.com/blog/2014/03/best-machine-embroidery-thread/

Hu J & Chung S (1998) , 'Drape Behavior of Woven Fabrics with Seams', Textile Research Journal , Volume: 68 issue: 12, P. 913-919

Manal, E, Seif, A , &.Nasr, M. M (2012) ,' Influence of embroidery stitches on the properties of textile fabrics' *Textile Asia* , 43(9):27-30 · October 2012

Nachiappan, S, Gnanavel, P&Ananthakrishnan, T (April 2009) , 'Effect of Seams on Drape of Fabrics' *'International Multi-Disciplinary Journal, Ethiopia* 'Vol. 3 (3), April, 2009 , P. 62-72

Oladipto, P.O, (2011) 'Embroidery as an embellishment in fabric decoration', Retrieved from https://www.google.co.in/url?sa=t&source=web&rct=j&url=http://www.globalacademicgroup.com/journals/pristine/EMBROIDERY%2520AS%2520AN%2520EMBELLISHMENT%2520IN%2520FABRIC%2520DECORATION.pdf&ved=2ahUKEwj_zrHy1bfbAhULq48KHdmJD8cQFjAKegQIABAB&usg=AOvVaw0J65TtWu1W_onD7JpyZInt

Radaviciene, S & Juciene, M (2013) , 'Buckling of the woven fabric inside an embroidered element', *' Proceedings of the Estonian Academy of Sciences, 2013*, 62, 3, P.187–192 , Retrieved from www.eap.ee/proceedings

Radaviciene S & Juciene M (2012) , 'Influence of Embroidery Threads on the Accuracy of Embroidery Pattern Dimensions', *Fibres & Textiles in Eastern Europe*' 2012, Vol. 20, No. 3 (92)

Radaviciene, S , Juciene, M , Juchneviciene, Z , Cepukone L , Kleveckas, T & Narviliene ,V (2012) , 'The Influence of the Properties of Embroidery Threads on Buckling of Fabric Inside of the Embroidered Element' , Materials Science (Medziagotyra) , Vol. 18, No. 4. 2012

Rasheed, A , Ahmad, S , Mohsin, M , Ahmed, F & Afzal, A (2014) , 'Geometrical model to calculate the consumption of sewing thread for 301 lockstitch , *The Journal of The Textile Institute* Volume 105, 2014 - Issue 12 , P. 1259-1264

Roberts, S. D (2010).,'Choosing Machine-Embroidery Threads' , *Threads* #91, P. 44-47 Retrieved, from http://www.threadsmagazine.com/item/4574/choosing-machine-embroidery-threads

Suggett, G, (2013) 'An introduction to Computerized Embroidery', Retrieved from https://www.wilcom.com/About/Blog/BlogArticle/tabid/123/ArticleId/47/An-introduction-to-Computerized-Embroidery.aspx

Yucel O (2012) , ' Effect of seamed viscose fabrics on drape coefficient', Tekstil 61 (1-6) P. 101-106.