

Study on the force required to thrust a sewing needle through various fabrics

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The effects of needle diameter, sewing yarn linear density and the number of fabric layers on the force required to thrust the needle through various fabrics have been studied using R/Set and M/Ball needles and six different fabrics (three plain woven, two twill woven and one plain knitted). The Box and Behnken factorial design was used for the study. It is observed that, in general, the thrusting force increases with the increase in number of fabric layers. Nevertheless, for M/Ball needle of the small size the thrusting force is same although the number of fabric layers increases. Sewing yarn linear density has no influence on the thrusting force except in case of twill weave polyester/wool fabric. The increase in needle diameter also increases the thrusting force. For a R/Set needle, increase in thrusting force is directly proportional to the increase in needle diameter, whereas for a M/Ball needle the difference in the thrusting force between small and medium needle sizes is very low.

Keywords: Factorial design, Needle diameter, Needle tip, Sewing yarn, Thrusting force

1 Introduction

During the sewing operation a sewing needle with yarn is thrust through the various fabric layers and the force required for needle penetration is related to the fabric sewability and needle heating. Considerable R&D effort has been directed towards the measurement and improvement of sewability and various publications have appeared in this respect, particularly on the sewability of knitted fabrics¹⁻⁷.

The present work deals with a study undertaken to investigate the influence of sewing needle type, needle size (diameter), sewing yarn linear density and the number of fabric layers on the force required for needle penetration using six different fabrics (three plain woven, two twill woven and one plain knitted). No work seems to have been published so far on the influence of these factors and their possible interactions on the sewability of fabrics using the Box and Behnken factorial experimental design⁸.

2 Materials and Methods

2.1 Fabrics

Six fabrics differing in composition, structure, picks/cm, ends/cm, weight and thickness were used (Table 1).

2.2 Sewing Needles

Round point needles differing in their tip shapes were used (Fig. 1). The first needle studied was the

R/Set needle, known as a Set Point needle. According to the Coats technical booklet⁹, it tends to spread the yarns apart without damaging them. The majority of the woven fabrics are sewn with Set Point needles often referred to as Cloth Point needles.

The second needle studied was the M/Ball needle, known as a Medium Ball Point needle (Fig. 1). According to the Coats technical booklet⁹, this tip point needle is used for sewing knitted fabrics because the rounded tip deflects the yarns, enlarging the loops without bursting them.

2.3 Needle Diameter

Needle diameter is defined by the metric needle size (Nm) being related to the diameter at the middle point of the blade above the scarf or short groove but below any reinforced part (Fig. 2) and is expressed in hundredths of millimeter.

$$\text{Needle size (Nm)} = \text{Diameter (mm)} \times 100$$

Needles of 60, 80 and 100 Nm were used for each type.

2.4 Sewing Yarn

Polyester staple fibre three-fold sewing yarns of three different linear densities, viz. 17×3 , 12.5×3 , 10×3 tex (corresponding to Nm 60/3, 80/3 and 100/3) were used.

Table 1—Fabric characteristics

Fabric composition	Structure	Threads/cm		Weight g/m ²	Thickness mm
		Warp	Weft		
Polyester/Cotton (70:30)	Plain weave	40	25	135	0.210
Polyester/Cotton (60:40)	Plain stitch	15	16	147	0.367
Wool	Plain weave	17	15	266	0.647
Polyester/Wool (55:45)	Twill weave	30	25	190	0.332
Cotton	Twill denim	30	20	452	0.853
Cotton	Plain weave	24	32	164	0.347

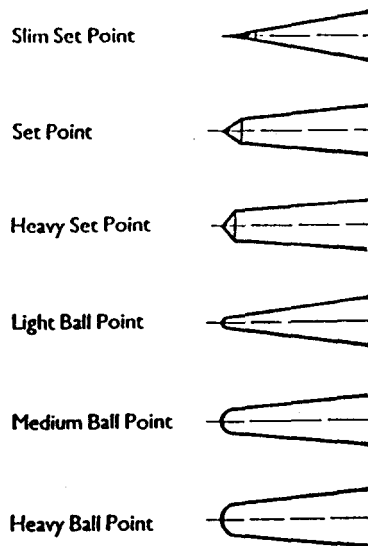


Fig. 1—Round needle types

2.5 Evaluation of Thrusting Force

The force required to thrust the sewing needle with yarn through different fabrics was measured using an Instron tensile tester with an especial device in which different fabric layers were fastened to be thrust. The sewing needle was held by an especial needle clamp fastened in the dynamometer. Tests were performed at 100 mm/min. Graphs which relate thrusting force with the needle penetration through fabric layers were obtained. These were similar to those shown in Fig. 3. It is observed from this figure that the first maximum is the highest one and it is related to the highest strength to be overtaken in sewing to thrust the fabric. The strength obtained in this 1st maximum was considered as the thrusting force and the mean value and coefficient of variation of ten trials for each experimental combination were calculated.

2.6 Factorial Design

In the Box and Behnken design⁸, the independent variables are selected at three codified levels, namely

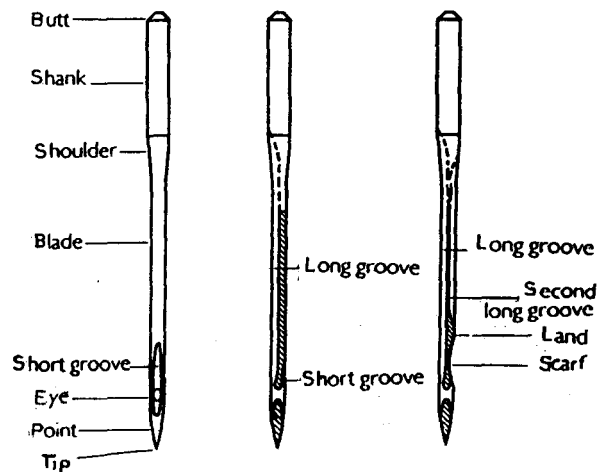


Fig. 2—Sewing needle

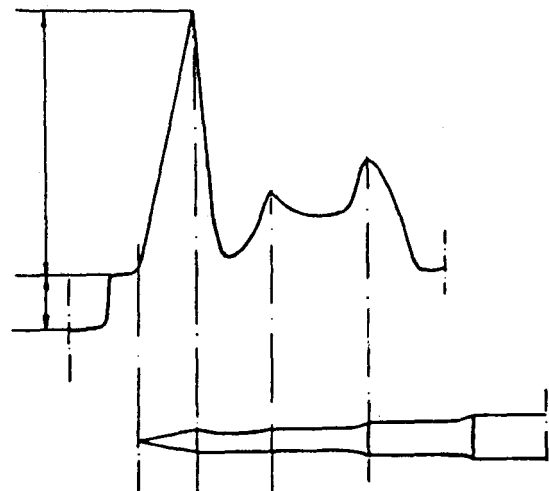


Fig. 3—Thrusting force vs. needle penetration through fabric layers

−1, 0 and 1. The response or dependent variable Y is given by a second order polynomial, i.e.

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3$$

where X_i = linear effect of i th variable

X_{ii} = quadratic effect of i th variable

$X_i X_j$ = linear $\times$ linear interaction of i th and j th variables

b_0 = independent term

b_i , b_{ii} and b_{ij} = regression coefficients associated with linear, quadratic and interaction equation variables.

To determine the regression coefficients, the response Y has to be found by using different experimental combinations of the variables under consideration. The experimental plan for three variables is given in Table 2 and the actual levels of the variables are given in Table 3.

3 Results and Discussion

The mean values and CV% of the force required to thrust R/Set needle and M/Ball needle through various fabrics are given in Tables 4 and 5 respectively. The results were fed to a HP85 micro-computer to obtain the regression coefficients of each variable and their significance levels. The statistical analysis yielded the regression equations with significant variables (at 10%, 5% and/or 1% level). These equations relate the thrusting force as the dependent variable (Y) with the linear and quadratic effects of the independent variables, namely the number of fabric layers (X_1 , X_1^2), the sewing yarn metric count (X_2 , X_2^2), the needle metric size or needle diameter (X_3 , X_3^2), and their linear $\times$ linear interactions ($X_1 X_2$, $X_1 X_3$ and $X_2 X_3$).

Table 6 gives the significance levels of the linear, quadratic and interactions effects for each type of needle tip and fabric.

The regression coefficients for each type of needle and fabric, and the correlation coefficient (r) between experimental and adjusted values are given in Table 7. It is observed that the value of r is greater than 0.9 except in the case of polyester/wool fabric with R/Set needle where for only two significant variables in the equation, r is 0.82.

3.1 Effect of Number of Fabric Layers (X_1 , X_1^2)

The number of fabric layers is very significant in its linear effect although in quadratic effect it is not significant (Table 6). This is to say that the thrusting force is proportional to the number of fabric layers to be thrust.

Nevertheless, with polyester/wool twill weave fabric when M/Ball needles are used, the number of fabric layers is not significant at all. Being a twill weave fabric with high porosity level, it would be reasonable to state that in this case the floating warp and weft yarns are easily deflected by needle

Table 2—Experimental plan for three variables

Experiment No.	Levels of variables		
	X_1	X_2	X_3
1	0	-1	-1
2	-1	0	-1
3	1	0	-1
4	0	1	-1
5	-1	-1	0
6	1	-1	0
7	0	0	0
8	0	0	0
9	0	0	0
10	-1	1	0
11	1	1	0
12	0	-1	1
13	-1	0	1
14	1	0	1
15	0	1	1

Table 3—Actual levels corresponding to coded levels

Variable	Level		
	-1	0	1
No. of fabric layers (X_1)	2	3	4
Sewing yarn metric count (X_2), Nm	60/3	80/3	100/3
Needle metric size (diameter as Nm) (X_3)	60	80	100

penetration and the thrusting force mainly depends on the friction between the needle and the fabric floating yarns. In this case, the needle penetration produces only a small yarn deflection without damaging the fabric yarns.

3.2 Effect of Yarn Metric Count (X_2 , X_2^2)

The effect of sewing yarn metric count on the thrusting force is not significant either in its linear or quadratic effect. Only in the case of polyester/wool woven fabric with M/Ball needle the linear effect is significant at 10% level. This confirms the aforementioned hypothesis that with this twill weave high porosity fabric, the thrusting force is mainly produced by the friction between the needle and the fabric yarns deflected during needle penetration. In this instance it seems logical that the sewing thread

Table 4—Mean values and CV% of the force required to thrust R/Set needle through various fabrics
Mean thrusting force, cN (CV%)

Polyester/Cotton plain weave	Cotton plain weave	Polyester/Wool twill weave	Wool plain weave	Polyester/Cotton plain stitch	Cotton twill denim
70.7 (28.37)	128.5 (23.14)	239 (10.60)	81 (27.58)	59 (23.57)	377 (11.80)
61.5 (18.00)	118.5 (12.74)	196.3 (12.05)	49 (30.35)	41 (43.33)	252 (27.10)
82 (11.57)	143 (11.08)	230 (9.27)	114.5 (27.03)	73 (61.53)	437 (26.74)
68 (6.20)	141 (16.02)	212.6 (7.73)	60 (36.64)	57.5 (44.20)	327 (25.87)
109 (14.74)	195.5 (19.49)	289.5 (9.86)	115 (17.63)	147 (32.71)	468 (27.67)
201.5 (11.82)	256 (16.13)	366.4 (12.61)	224 (21.48)	258.5 (31.40)	737 (17.22)
127.5 (17.37)	218.5 (19.33)	266.5 (19.06)	218 (26.71)	167 (27.08)	675 (20.72)
144 (15.60)	253 (19.10)	266.8 (18.67)	190 (34.40)	186.5 (34.54)	740 (12.92)
122 (16.75)	193.5 (16.10)	227.1 (14.74)	203 (30.70)	229.5 (72.28)	621 (25.82)
107.9 (14.31)	137 (19.17)	190.1 (15.06)	118 (35.18)	146 (52.98)	448 (24.58)
185.5 (7.67)	277 (25.32)	266.6 (20.77)	239.5 (17.37)	231.5 (37.27)	819 (35.11)
193.5 (12.37)	294.5 (40.64)	359.9 (18.23)	288.5 (23.09)	274.5 (30.10)	811 (32.30)
171 (16.41)	215.5 (7.37)	239.6 (15.99)	162 (41.18)	204 (49.00)	669 (29.90)
282 (12.95)	404 (32.92)	243.1 (19.02)	375 (42.64)	451 (36.44)	840 (25.93)
259 (19.47)	257.5 (14.80)	411.5 (16.20)	267.5 (29.81)	284.5 (61.78)	765 (28.10)

Table 5—Mean values and CV% of the force required to thrust M/Ball needle through various fabrics
Mean thrusting force, cN (CV%)

Polyester/Cotton plain weave	Cotton plain weave	Polyester/Wool twill weave	Wool plain weave	Polyester/Cotton plain stitch	Cotton twill denim
202 (6.72)	135.5 (11.06)	196.5 (15.08)	163.5 (13.98)	115 (26.49)	357 (16.95)
168 (8.56)	110.5 (18.41)	141.5 (8.0)	127.5 (12.43)	53.5 (28.91)	270 (22.60)
207 (6.36)	233.5 (10.87)	176.5 (9.26)	176 (24.06)	93 (27.55)	525.5 (21.90)
151.5 (7.63)	195.5 (18.93)	199.5 (14.73)	193 (7.04)	70 (26.08)	401 (21.52)
176.5 (9.64)	204.5 (8.11)	214 (12.40)	129.5 (11.14)	157.5 (19.53)	406.5 (21.31)
239 (7.88)	152.5 (32.28)	268 (14.85)	193 (16.48)	231 (37.52)	477.5 (24.08)
179.5 (19.0)	141 (26.63)	232.5 (12.05)	136 (17.66)	200 (35.04)	425.5 (17.88)
149 (17.02)	122 (27.47)	155.5 (17.38)	158.5 (20.81)	173 (22.77)	431 (23.44)

(contd)

Table 5—Mean values and CV% of the force required to thrust M/Ball needle through various fabrics — *Contd*

Mean thrusting force, cN (CV%)

Polyester/Cotton plain weave	Cotton plain weave	Polyester/Wool twill weave	Wool plain weave	Polyester/Cotton plain stich	Cotton twill denim
151.5 (14.26)	118 (63.39)	177 (17.01)	148.5 (13.75)	181.5 (15.69)	512 (16.77)
131.5 (13.54)	92 (58.66)	123.5 (15.27)	109.5 (20.58)	140.5 (16.13)	388 (24.57)
178.5 (9.06)	144 (38.42)	146.5 (20.03)	171.5 (13.54)	223.5 (22.50)	548 (19.69)
365.5 (10.59)	432.5 (13.46)	474 (26.28)	428 (21.01)	479 (36.48)	690 (32.21)
287.5 (11.1)	312 (13.81)	379.5 (22.11)	344 (24.08)	260 (15.18)	555.5 (34.77)
559 (15.76)	510 (16.04)	489.5 (12.30)	504 (22.81)	592 (30.0)	1046 (32.89)
316.5 (21.12)	363 (9.46)	436 (29.05)	375 (36.39)	430 (33.26)	845 (39.73)

Table 6—Significance levels (%) of linear, quadratic and interaction effects for needle and fabric types (F — Sbedecor test)

Needle	Fabric	X_1	X_2	X_3	X_1^2	X_2^2	X_3^2	X_1X_2	X_1X_3	X_2X_3
R/Set	Polyester/Cotton plain weave	1	—	1	—	—	—	—	5	10
	Cotton plain weave	1	—	1	—	—	—	—	5	—
	Polyester/Wool twill weave	5	—	1	—	—	—	—	—	—
	Wool plain weave	1	—	1	—	—	—	—	5	—
	Polyester/Cotton plain stich	1	—	1	—	—	—	—	1	—
	Cotton twill denim	1	—	1	—	—	5	—	—	—
M/Ball	Polyester/Cotton plain weave	5	—	1	—	—	1	—	5	—
	Cotton plain weave	10	—	1	—	—	1	—	—	—
	Polyester/Wool twill weave	—	10	1	—	—	1	—	—	—
	Wool plain weave	1	—	1	—	—	1	—	10	—
	Polyester/Cotton plain stich	1	—	1	—	—	5	—	5	—
	Cotton twill denim	5	—	1	—	—	5	—	—	—

carried by needle through fabric layers increases the friction between the sewing needle with thread and fabric yarns. The friction will increase as the sewing thread grows coarser.

3.3 Effect of Needle Size (X_3 , X_3^2)

The effect of needle size on the thrusting force is significant for all types of fabric. In the case of R/Set needle, the linear effect is significant for all types of fabric but the quadratic effect is significant only for the twill weave denim fabric (Table 6). The different behaviour of this fabric in relation to needle size could be explained by the very different characteristics of this fabric (a very high mass per unit area and thickness) in relation to the others.

In the case of M/Ball needle, both the linear and the quadratic effects are very significant, i.e. the thrusting

force for the medium size needle is similar to that for the low size needle but very different to that for the high size needle. There is no proportional increase between the thrusting force and the needle size.

3.4 Interactions

Of the three interactions considered, only the $X_1 X_3$ is significant. When the number of fabric layers increases, the effect of needle size influences the thrusting force in a much more strong way. This occurs when the plain woven and knitted fabrics are thrustured with R/Set needle. When the twill weave fabrics are thrustured this interaction is not significant.

While using M/Ball needle this interaction occurs but with a lower significance level. For polyester/cotton plain weave, it maintains a 5%

Table 7—Regression coefficients for each type of needle and fabric

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3$$

Needle	Fabric	b_0	b_1	b_2	b_3	b_{11}	b_{22}	b_{33}	b_{12}	b_{13}	b_{23}	Correlation coefficient
R/Set	Polyester/Cotton plain weave	145.63	37.70	—	78.00	—	—	—	—	22.63	16.88	0.98
	Cotton plain weave	209.68	54.11	4.47	76.97	-2.66	13.52	-2.66	9.31	46.33	—	0.96
	Polyester/Wool twill weave	276.34	46.33	—	69.54	—	—	—	—	—	—	0.82
	Wool plain weave	178.67	60.50	—	98.56	—	—	—	—	36.88	—	0.98
	Polyester/Cotton plain stitch	190.70	65.75	—	122.94	—	—	—	—	53.75	—	0.98
	Cotton twill denim	653.21	129.00	—	207.00	-6.47	-6.47	-84.08	—	—	—	0.95
M/Ball	Polyester/Cotton plain weave	162.26	52.50	—	100.00	8.57	8.57	111.44	—	58.13	—	0.95
	Cotton plain weave	126.12	40.13	—	117.81	11.47	11.47	148.94	—	—	—	0.94
	Polyester/Wool twill weave	178.03	—	-30.88	133.13	9.50	9.50	123.46	—	—	—	0.96
	Wool plain weave	137.92	41.75	—	123.88	10.74	10.74	139.60	—	27.88	—	0.99
	Polyester/Cotton plain stitch	180.43	66.00	—	178.69	5.78	5.77	75.08	—	73.13	—	0.99
	Cotton twill denim	444.82	122.13	—	197.88	10.05	10.05	130.67	—	—	—	0.94

significance level (Fig. 4). For 100% cotton plain weave, the 5% level of significance with a R/Set needle decreases to a non-significant level with a M/Ball needle. For 100% wool plain weave, the 5% significance level with a R/Set needle decreases to a 10% significance level with a M/Ball needle. For polyester/cotton (60:40) plain stitch, the 1% level of significance obtained with a R/Set needle decreases to the 5% level with a M/Ball needle.

3.5 Needle Penetration Mechanism

Considering the significant effects and interactions it can be stated that there are two extreme mechanisms in the needle penetration through fabrics. In the first mechanism where only the deflection of fabric yarns is produced, sewability is very good and needle heating low. In the second mechanism where besides yarn deflection, fabric bursting or yarn breakage is produced, sewability is low and needle heating high.

It may be stated that with a M/Ball needle the second mechanism prevails although it is necessary to consider the fabric structure. According to the fabric structure (weave, density, cover factor, etc.) the penetration mechanism differs with the same needle. Contrarily, with a R/Set needle, the first mechanism prevails although the fabric structure has to be considered too.

It seems that the thrusting force mainly depends on the needle and, to some extent, on the fabric composition and weave. Therefore, if we look for low thrusting force, i.e. good sewability or low needle heating, then according to the fabric characteristics and the number of fabric layers to be sewn, the right type and size of the needle (i.e. R/Set or M/Ball) should be chosen.

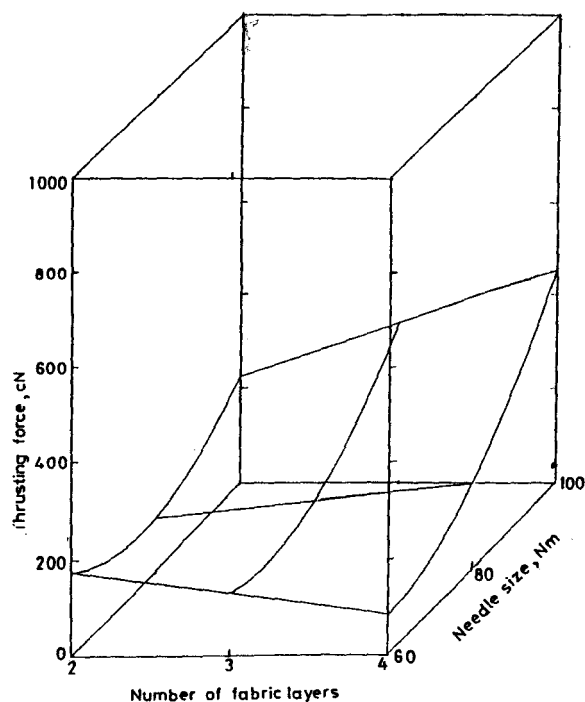


Fig. 4—Thrusting force for polyester/cotton plain weave and M/Ball needle

4 Conclusions

4.1 There are two mechanisms of needle penetration: One based on fabric yarn deflection and the other on fabric bursting or yarn breakage. It seems that these mechanisms mainly depend on the fabric structure, the first one on fabrics with floating yarns (twill weave fabrics) and the second one on fabrics without floating yarns (plain weave and knitted fabrics). Nevertheless, other fabric characteristics

such as density, thickness, cover factor and composition also affect these mechanisms.

4.2 The number of fabric layers has a linear effect on the thrusting force whichever needle is used.

4.3 The needle size has a linear effect on the thrusting force when a R/Set needle is used, and linear and quadratic effects when a M/Ball needle or a R/Set needle with high density fabrics (e.g. jeans) is used.

4.4 For plain weave and knitted fabrics, an interaction between the number of fabric layers and needle size has been observed for both types of needle used, the interaction being lower with the M/Ball needle.

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