ELONGATION CONTROL IN SPUN YARNS

By

G.MAHAALINGAM
Reg.No.71202502003

of

KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE

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BONAFIDE CERTIFICATE

Certified that this project report titled "ELONGATION CONTROL IN SPUN YARNS" is the bonafide work of Mr.G.Mahaalingam who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

19/6/04

Prof.Dr. J. Srinivasan

Professor

(Supervisor)

Prof.Dr.V.Natarajan

Professor & Head

Viva-Voce Examination is Conducted on 18.06.04

ABSTRACT

The elongation of yarn is one of the very important yarn characteristics. This parameter has assumed a lot of significance mainly because this is one of the key parameters affecting the performance of high-speed shuttle and shuttleless looms.

Based on the findings of yarn elongation values at cop stage, cone stage and pirn stage it was observed that 'ring frame has the maximum scope for improving yarn elongation'. In the present study, a number of trials were conducted at the ring frame by varying the important process parameters such as spindle speed, traveler number and twist multiplier. Two yarn counts viz. 40^s and 60^s Ne was chosen for the study.

It was found out from the results that, the yarn elongation increased with decrease in spindle speed. Also lighter the traveler weight, increase in yarn elongation was observed. Also increase in the twist multiplier improved the yarn elongation.

Key words: Quality, Cotton fiber, Yarn, Elongation.

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CHAPTER 1

INTRODUCTION

Due to globalization and opening of the Indian economy, there has been a distinct and positive shift from quantity to quality. Quality is a much – acclaimed and at the same time much-despise word. Quality in the true sense of the word is the ability of the product to satisfy the requirements expected from it. Yes, the present textile industry is faced with problems of stiff global competition, demand of quality standards and reliability of products at international level. Proper quality right from the beginning to the end has become essential to meet recent challenges. The main and major challenge to cotton yarn is "BREAKING ELONGATION".

The elongation requirements of 100% cotton yarn for weaving and knitting as specified by many importing countries varies between 5% and 5.5%. However, the average elongation values obtained for Indian yarn lies in the range of 4% to 4.5%.

Two among the important properties resorted for evaluating a yarn is the single yarn tenacity and elongation. In post spinning process such as weaving the yarn is subjected to peak loads. With the advent of high-speed shuttleless looms, yarn elongation has assumed considerable significance because it is one of the major yarn characteristics affecting loom performance. In order to withstand strain in these processes without being damaged or breaking, a yarn must have a certain minimum tensile strength and minimum elongation so that the number of end breaks and consequently the number of machine stops could be controlled at a minimum level. Hence single yarn strength and elongation are critical factors.

Some of the fiber and process variables affecting breaking elongation of spun yarn (cotton) are enumerated in this project.

CHAPTER 2

LITERATURE REVIEW

2.1. Breaking Extension

Our spun yarns are all bound to extend under load. The extension is classified in to two categories.

1. Elastic part
2. Plastic or permanent part

Elastic part is recoverable when stress is removed and plastic part is permanent set.

Elastic recovery = Elastic extension / Total extension

Complete recovery will then have the value 1 (or 100 %), incomplete recovery will
have a proportionately lower fraction, and no recovery at all will have the value zero.

2.2. Fibre Elongation at Various Stages of Spinning

From the studies conducted by Deepali Plawat, J.M.Grover and A.J.Sonagra (2002), to identify which stage of spinning has maximum scope for improving elongation the following results are obtained.

(a) Maximum drop in fibre elongation was at ring frame stage. It ranged from 16 to 30%

(b) The drop in fibre elongation from mixing to ring frame front roller was from 35 to 42%

(c) Yarn elongation was equal to or higher than the fibre elongation at ring frame stage.

(d) Elongation realization percentage i.e. ratio of yarn elongation to fibre elongation expressed as percentage varied from 57 to 90%

2.3. Methods for improving the breaking elongation of single yarn

From the studies conducted by N.Arun (1999), the following factors are taken in to consideration to improve the breaking elongation.

2.3.1. Fibre properties:

2.3.1.1. Staple length of fibre

The staple length of the fibre has great influence towards the elongation at break of the yarn. The staple length of the fibre differs from one variety to another variety of cotton and also within a lot. When the staple length of the fibres is more, it will create better inter fibre cohesiveness. This increases in twist per inch, gives the ultimate strength and breaking elongation of yarn.

2.3.1.2. Micronaire of the fibre

For the same count, the yarn breaking force is usually higher for the finer fibre. It can be seen that the breaking elongation of the yarn is increased when the micronaire value of the fibre decreases. The relationship between the micronaire of the fiber and breaking elongation of the fibre can be explained as follows – Micronaire in mere number is inversely proportional to breaking elongation. The following table shows the relationship between micronaire of fibre and breaking elongation of yarn.

2.3.1.3. Uniformity ratio of the fibre

Uniformity ratio is directly proportional to the spinnability of the fibre. The yarn breaking force is higher when lower amount of short fibre is present in the yarn. It is seen that the breaking elongation of yarn is increased, when the

2.3.1.4. Maturity of the fibre

The fibres that are having good maturity property will orient well during processing through different machines. It will increase the breaking strength of the yarn. For the same count, the yarn breaking elongation is usually higher when we choose the higher maturity grade fibre.

2.3.1.5.Fibre elongation

Fiber elongation is the strength of the single fiber in the lengthwise direction. The breaking elongation at break of the yarn is higher, when the fibre elongation is high. Because during tensile testing, the fibres slide among from each other but some of them break. For this, the fibre elongation is very important. Scattering of fibre elongation break point should be prevented to improve yarn elongation. Hence the high elongation of raw fibre gives more elongation at break point in the yarn.

2.3.2. Machinery parameters:

2.3.2.1. Removal of noil %

During the combing process, the maximum possible noil% should be taken to achieve the acceptable breaking elongation in the final yarn. Hence combing process is a way to improve the elongation at break of the yarn.

2.3.2.2.Traveller number used in ring frames

Traveller number indicates the mass of the traveller. If the traveller mass is high, it will lead to high yarn tension and more end breakages and vice versa. Accordingly, the mass of the traveller must be matched exactly to both the yarn and spindle speeds so that, optimum traveller weight is to be chosen depending on the requirements to achieve the desirable breaking elongation. Use of

2.3.2.3. Spindle speed of ring frames

Speed of the spindle is also one criterion, which affects the breaking elongation of the yarn. When the spindle is rotated at higher speed, the surface speed of the traveller increases. This increase tends to raise the tension in the yarn. As a result of this, the yarn is stretched and the breaking elongation is reduced. By reducing the spindle speed, the tension on the yarn becomes optimum and the breaking elongation raises from the normal level.

2.3.2.4. Ring rail speed

Decrease in the ring rail speed causes a marginal increase in yarn elongation. This is due to reduction in the rate of change of balloon height during cop build, which in turn helps to reduce the change of ballooning tension.

2.3.3. Other parameters:

2.3.3.1. Twist multiplier given to the yarn

The T.M given to the material plays an important role in the elongation of the yarn. The elongation of the yarn mainly depends upon the frictional force between the fibres. We may conclude that if T.M is increased, the elongation at break will improve.

2.3.3.2. Count to be spun

The elongation of the yarn at break will vary according to the count spun for a particular mixing. If under spinning is carried out in processing, it means the elongation will be more, because the inter fibre friction is more in the under spinning. If over spinning is carried out in mixing it will lead to drop in elongation. Optimum count must be therefore spun to the mixing to improve the elongation of the yarn and economical to the mill. Approximately the yarn elongation drops by

2.3.3.3. Relative Humidity in the department

All the cotton absorbs moisture from their ambient surroundings. The percentage component of moisture depends upon the type of fiber, the relative humidity and the temperature. To improve the breaking elongation of the yarn, the humid condition should be maintained as slightly more than the normal humid condition.

2.3.3.4. Heat setting of the yarn

After spinning process and before entering in to the post spinning process, heat setting is given to the yarn. The main purpose of heat setting is to set the twist and to avoid snarling, and also the strength is increased during the process. Here the setting time plays a vital role. The percentage increase in the elongation depends on the time period for which it is processed. The time is directly proportional to the elongation percentage of the yarn.

2.3.3.5. Yarn conditioning

Textile fibres are hygroscopic in nature. They absorb moisture when it is exposed to the higher relative humidity condition inside the conditioning room. It results in improving the strength of the yarn and elongation. It is observed that there is better improvement in the breaking elongation, according to time dependent of conditioning.

2.3.3.6. Improving the breaking elongation of yarn by doubling

When two or more identical yarns are combined together, they loose their individual, identical specialties and become merely a part of the final thread. Yarn elongation at break can be controlled within a certain limit and the improvement ...ly depends on the amount of twist given to the yarn.

2.4. Stretching of yarn during weaving preparatory processes

Weaving preparatory processes involves tensioning / stretching.

Process Average tension

Winding - 8 to 10 % of breaking elongation
Pirn winding - 15 % of breaking elongation
Warping - 5 % of breaking elongation
Sizing - 10 to 15 % of breaking elongation (Stretch - 1 %)

2.4.1. Recoverable stretch

Depending upon the basic fiber and yarn characteristic the elastic extension can vary from 30 to 85 %. (Polyester fiber will have more elastic extension than cellulose fibers).

2.4.2. Causes for variability of tension / stretch in processes

- In winding process, due to unwinding tension variation from cop tip to bottom there is wide variation in winding tension, when add-on tension is kept constant (variation in tension – 50 to 60 %). The yarn from supply package passes through the tensioner in order to produce the effective winding and firm package. Due to excess winding tension, the yarns get stretched and this stretch is mainly responsible for the loss in yarn elongation.
- In warping process, the cones kept in the front row and the cones kept in the back row under go different unwinding tension due to differential air drag involved.
- In sizing process, to unwind the yarn from braked warp beam and to wind the yarn tightly on weavers beam tension has to be applied.
- Creel stretching varies due to improper control of brakes throughout

2.5. Effect of stretch on breaking elongation of sized yarns and their weavability

From the studies conducted by S.K.Aggarwal and G.Balasubramanian (1986), the effect of stretch on breaking elongation of sized yarns and their weavability was studied. Beyond a certain level, warp stretch during sizing adds substantially to the warp breakage rate in weaving. This increase in breakage rate has been attributed to an excessive loss in elongation resulting from excessive stretch.

A high level of stretch during sizing not only reduces the average level of the elongation of the warp yarn, but also renders the individual threads to be more non-uniform in terms of breaking elongation. This increase in the non-uniformity is the result of an abrupt increase in the frequency of threads with elongation below a certain critical level. Such low – elongation threads would appear to be a cause for the excessive warp breakage rate resulting from excessive starch in sizing. One cause of the occasionally observed intervals of very high warp breakage rate in a given weaver's beam could be the presence in the beam of threads of very low elongation.

2.6. Measurement of yarn elongation:

Normally the instruments used for testing yarn strength also give yarn elongation. The common instruments used for testing single yarn strength and elongation is Tensojet, Tensorapid, Statimat and Dynamometer.

CHAPTER 3

RESEARCH OBJECTIVES

(a) Identification of the process/stage where the elongation drop is maximum

(b) Optimization of parameters for the identified process

(c) Hypothesizing various theories for reduced yarn elongation

CHAPTER 4

METHODOLOGY

4.1. Process parameters:

Based on the findings of yarn elongation values at cop stage, cone stage and pirn stage and hitherto published literature 'ring frame has the maximum scope for improving yarn elongation', a number of trials were conducted at ring frame by varying the following important process parameters:

(a) Spindle speed
(b) Traveler number
(c) Twist multiplier

Each of the parameters independently affected yarn elongation marginally, however, it gave an important clue to the direction of work. Therefore, combined effect of all these parameters was assessed. Taking in to consideration the sample preparation, the three process parameters are varied for three ranges as follows. By doing so it leads to large sample size.

Serial Number	Spindle Speed	Traveler Number	Twist multiplier
1.	14000 rpm	10/O	3.9
2.	15000 rpm	12/O	4.1
3.	16000 rpm	14/O	4.3

In order to reduce the sample size and to have an optimized result a model named "BOX- BEHNKEN DESIGN" has been adopted. (Refer Annexure 1)

The obtained samples are analyzed and elongation values are noted. The ... incorporated with the above said variables using "SYSTAT" software and general regression equation is obtained. The results are obtained in graphical form by applying the general equation to software "MATLAB".

4.2. Fibre parameters:

Fibre type	= cotton.
Roving hank	= 1.95, 1.6.
Mixing	= 60^s ,40^s mixing.

4.3. Machine parameters:

Ring frame

Make	= Trytex, Coimbatore.
Yarn count	= 60, 40^s Ne.
Break draft	= 1.2
Twist direction	= 'Z'
Spinning angle	= 10^0
Drafting angle	= 45^0
Yarn contraction	= 2.9
Drafting system	= Suessen WST Drafting system

Computerised Single thread strength tester

Make	= Statex Tensostate – Junior,
Parameters measured	= Single yarn strength, Yarn elongation
Load cell	= Max. Capacity 10Kg
Specimen jaw	= Pneumatically operated
Gripping force	= Up to a maximum of 165 N
Pneumatic pressure	= Max. 6 bars
Pretension	= Adjustable, automatically controlled
Testing speed	= 100mm/min – 1000mm/min

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1. Experimental design for three variables (60^s Ne)

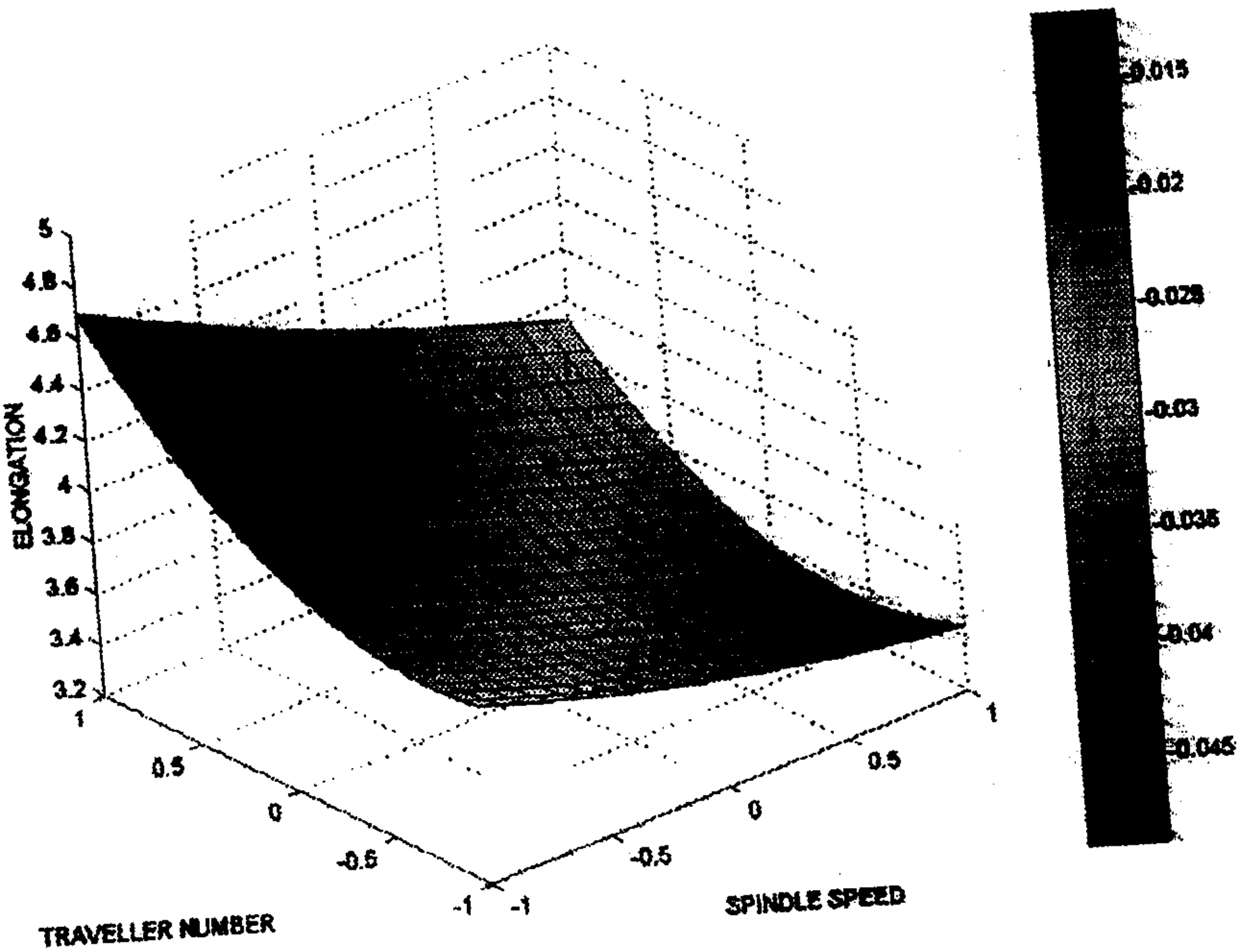
Serial Number	Spindle Speed (rpm)	Traveler Number	Twist Multiplier	Actual Count	Elongation (%)
1.	14000	14/O	4.1	60.5	4.81
2.	16000	14/O	4.1	60.1	4.24
3.	14000	10/O	4.1	61.0	3.74
4.	16000	10/O	4.1	60.8	3.51
5.	14000	12/O	3.9	59.8	4.31
6.	16000	12/O	3.9	61.4	3.69
7.	14000	12/O	4.3	60.0	4.09
8.	16000	12/O	4.3	59.5	3.52
9.	15000	14/O	3.9	60.2	4.48
10.	15000	10/O	3.9	60.6	3.70
11.	15000	14/0	4.3	61.5	4.98
12.	15000	10/O	4.3	60.6	3.39
13.	15000	12/O	4.1	61.5	3.95
14.	15000	12/O	4.1	60.9	3.74
15.	15000	12/0	4.1	60.7	3.52

5.1.1. Regression Equation

$$Y=3.737-0.249A+0.521B-0.025C+0.052A^2+0.287B^2+0.114C^2-0.085AB+0.012AC+0.203BC$$

Effect of spindle speed and traveler number on yarn elongation

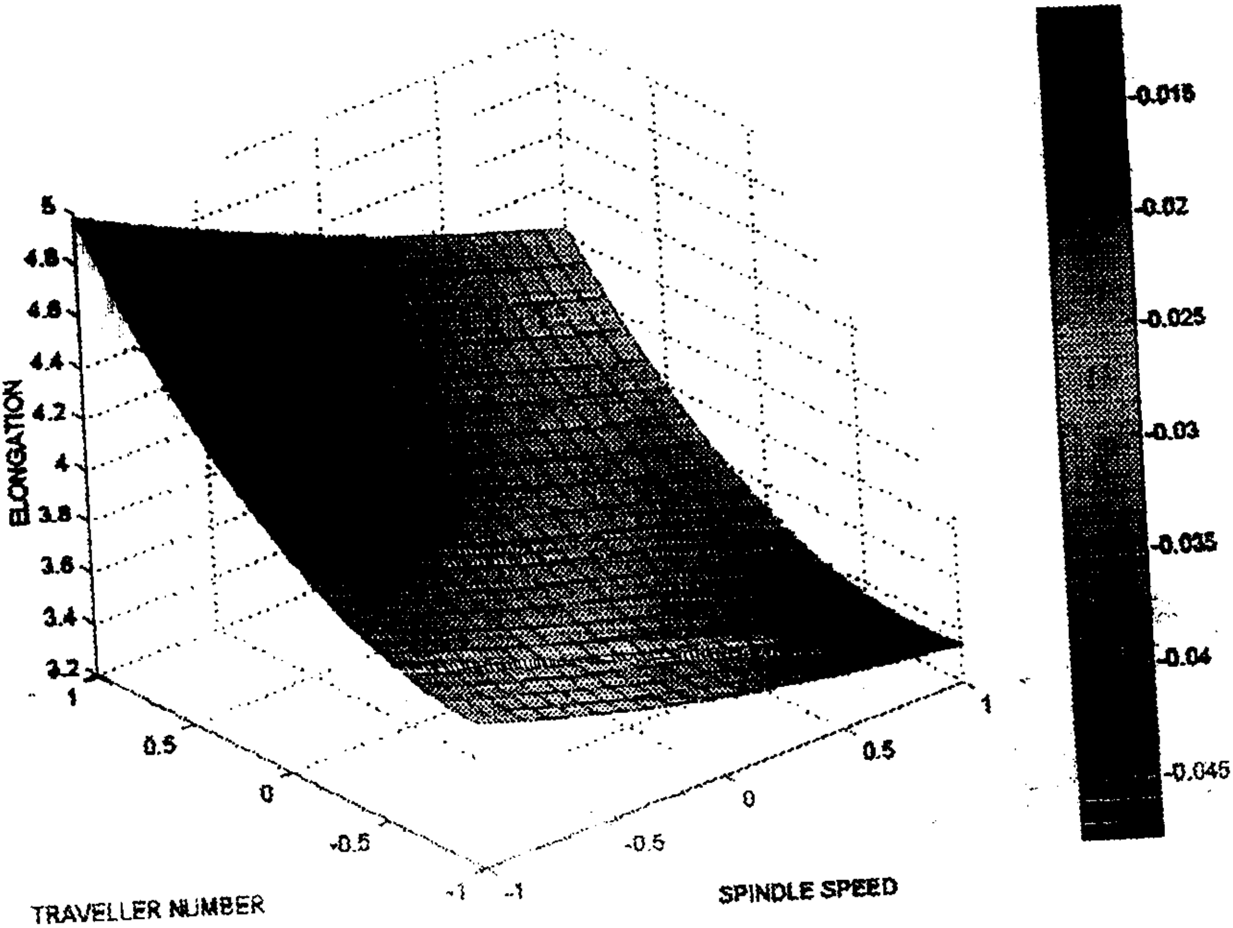
Twist Multiplier = 3.9



It can be observed from the graph that for a given TM value of 3.9, with the increase in the spindle speed from 14000 to 16000 rpm the yarn elongation is found to decrease. Also the yarn elongation value increases with the increase in the traveler number from 10/O to 14/O. This means the yarn elongation increases at lower spindle speeds. The effect of change in spindle speed on yarn elongation is found to be more than that of traveler number.

Effect of spindle speed and traveler number on yarn elongation

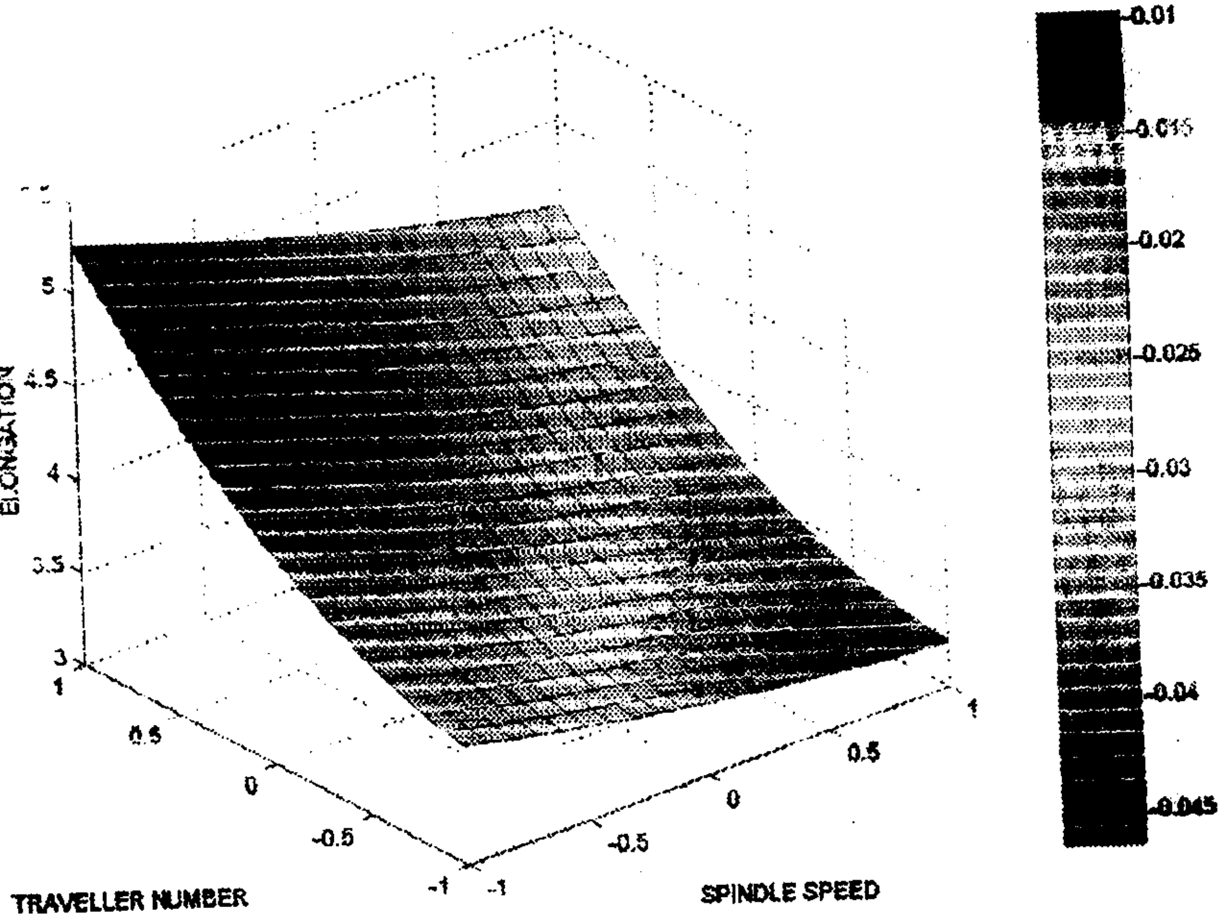
Twist Multiplier = 4.1



At a TM of 4.1, the yarn elongation was found to decrease with increasing spindle speeds from 14000 to 16000 rpm. The yarn elongation was found to increase with increasing traveler number from 10/O to 14/O. At this particular value of TM, the effect of traveler number was found to be lesser than that of

Effect of spindle speed and traveler number on yarn elongation

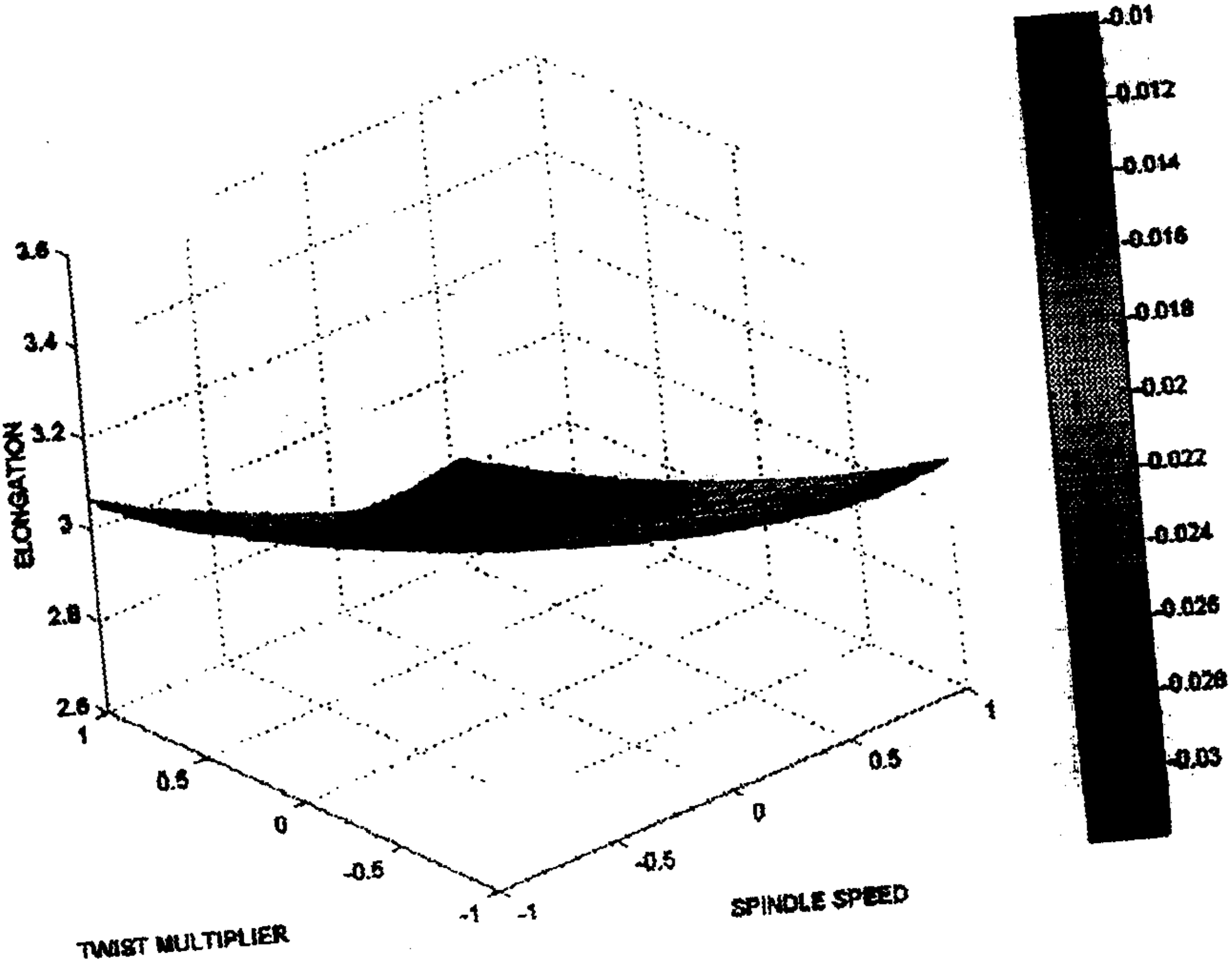
Twist Multiplier = 4.3



As per the graph it can be observed that at a TM value of 4.3, the yarn elongation drastically fell with increasing spindle speed from 14000 to 16000 rpm. The change in traveler number did not show significant change in yarn elongation. Thus it can be seen that the effect of spindle speed at this particular value of TM is much more pronounced as compared to traveler number.

Effect of spindle speed and Twist multiplier on yarn elongation

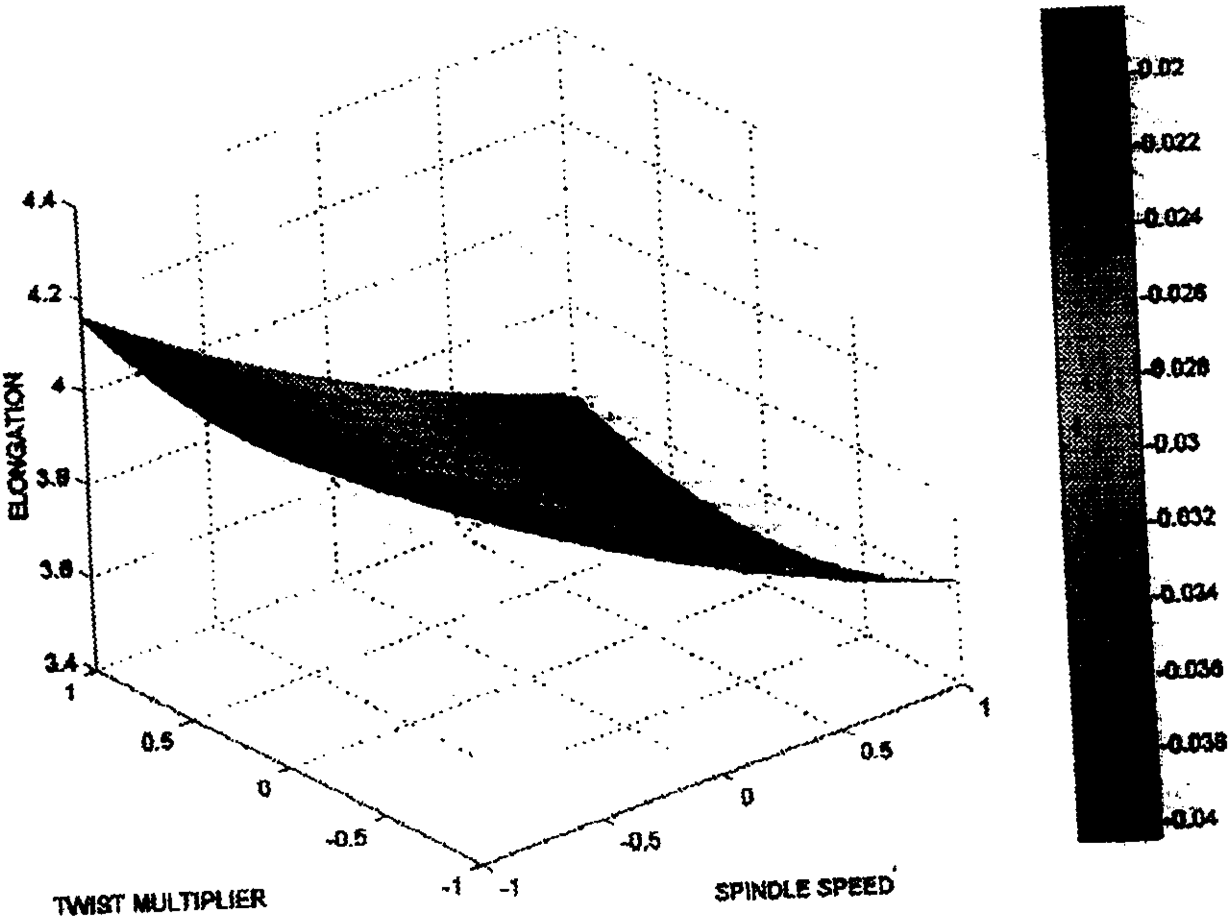
Traveler number = 10/O



The effect of spindle speed and TM at a given traveler size of 10/O can be seen in the graph. It is observed that the yarn elongation value decreased gradually when the spindle speed is increased from 14000 to 16000 rpm. The change in yarn elongation was curvilinear when the TM is increased from 3.9 to 4.3. Thus for a given traveler number, the influence of spindle speed and TM was

Effect of spindle speed and Twist multiplier on yarn elongation

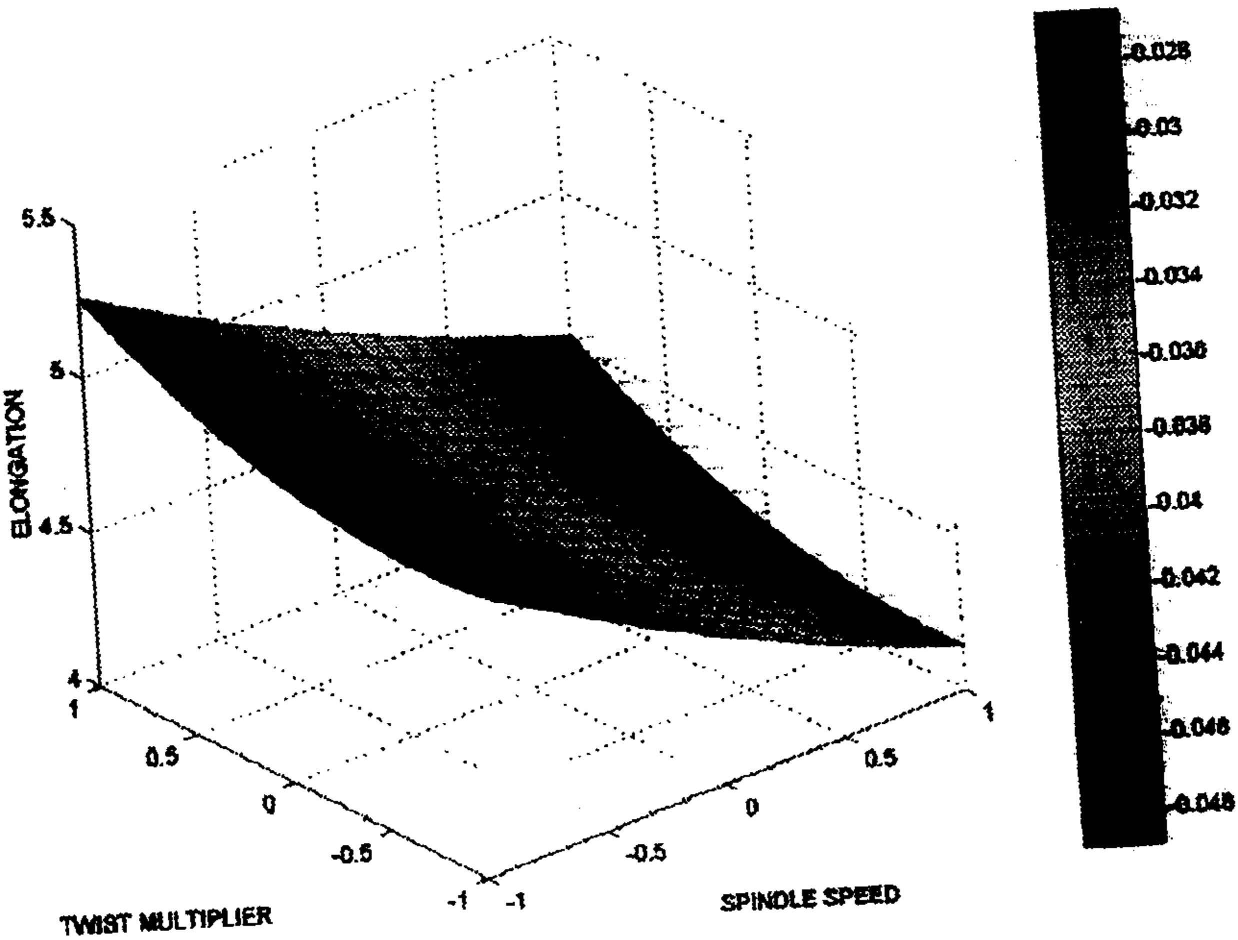
Traveler number = 12/O



The effect of spindle speed and TM at a given traveler size of 12/O can be seen in the graph. It is observed that there is a drastical decrease in yarn elongation when spindle speed is increased from 14000 to 16000 rpm. The yarn elongation steadily increases with change in TM values from 3.9 to 4.3. Thus for the given traveler number the influence of spindle speed is more pronounced as ... change in TM value.

Effect of spindle speed and Twist multiplier on yarn elongation

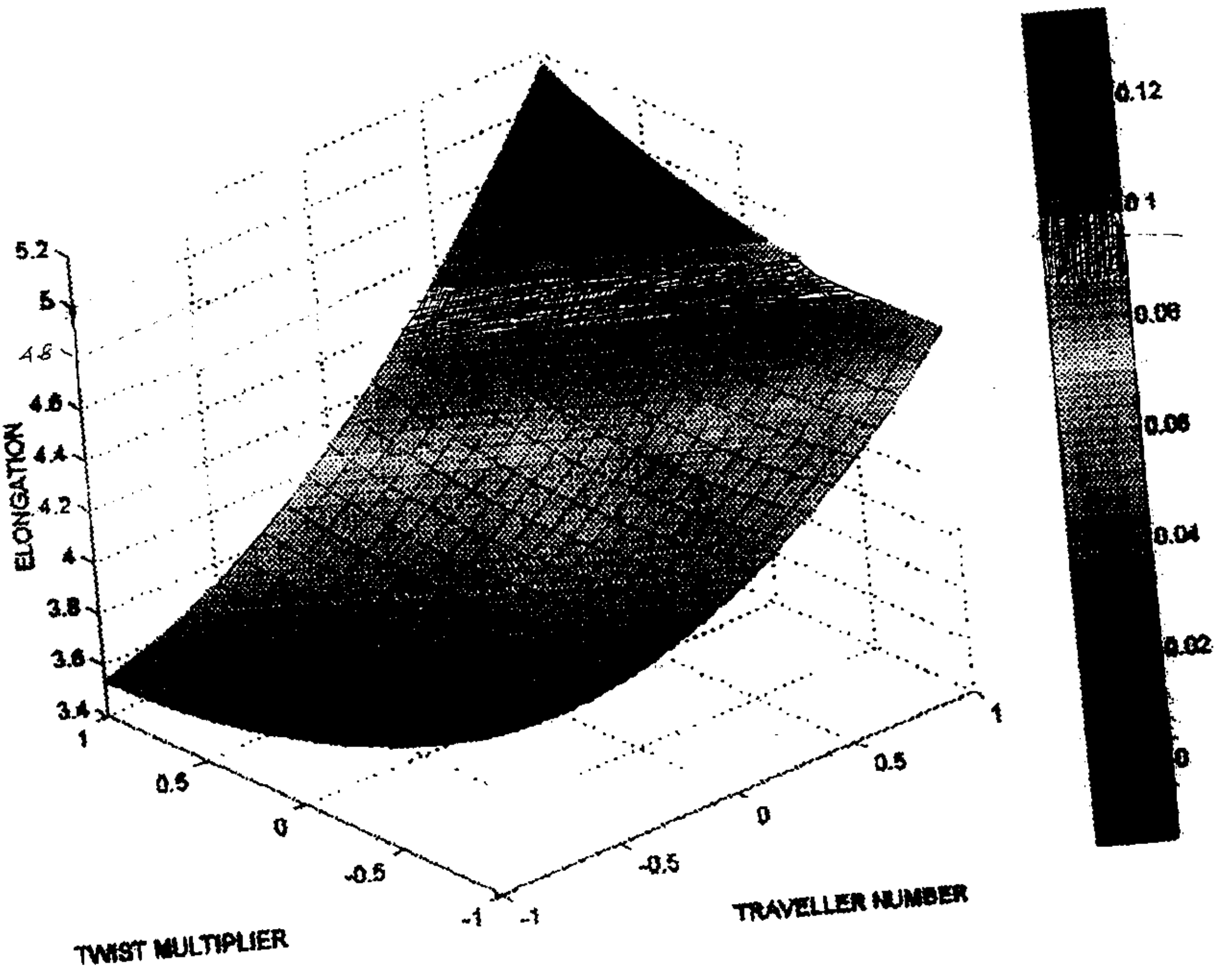
Traveler number = 14/O



As per the graph at a given traveler number of 14/O, the yarn elongation abruptly decrease with increase in spindle speed from 14000 to 16000 rpm. The yarn elongation value increases almost linearly with increase in TM values between 3.9 and 4.3. The effect of spindle speed is much more pronounced than

Effect of traveler number and Twist multiplier on yarn elongation

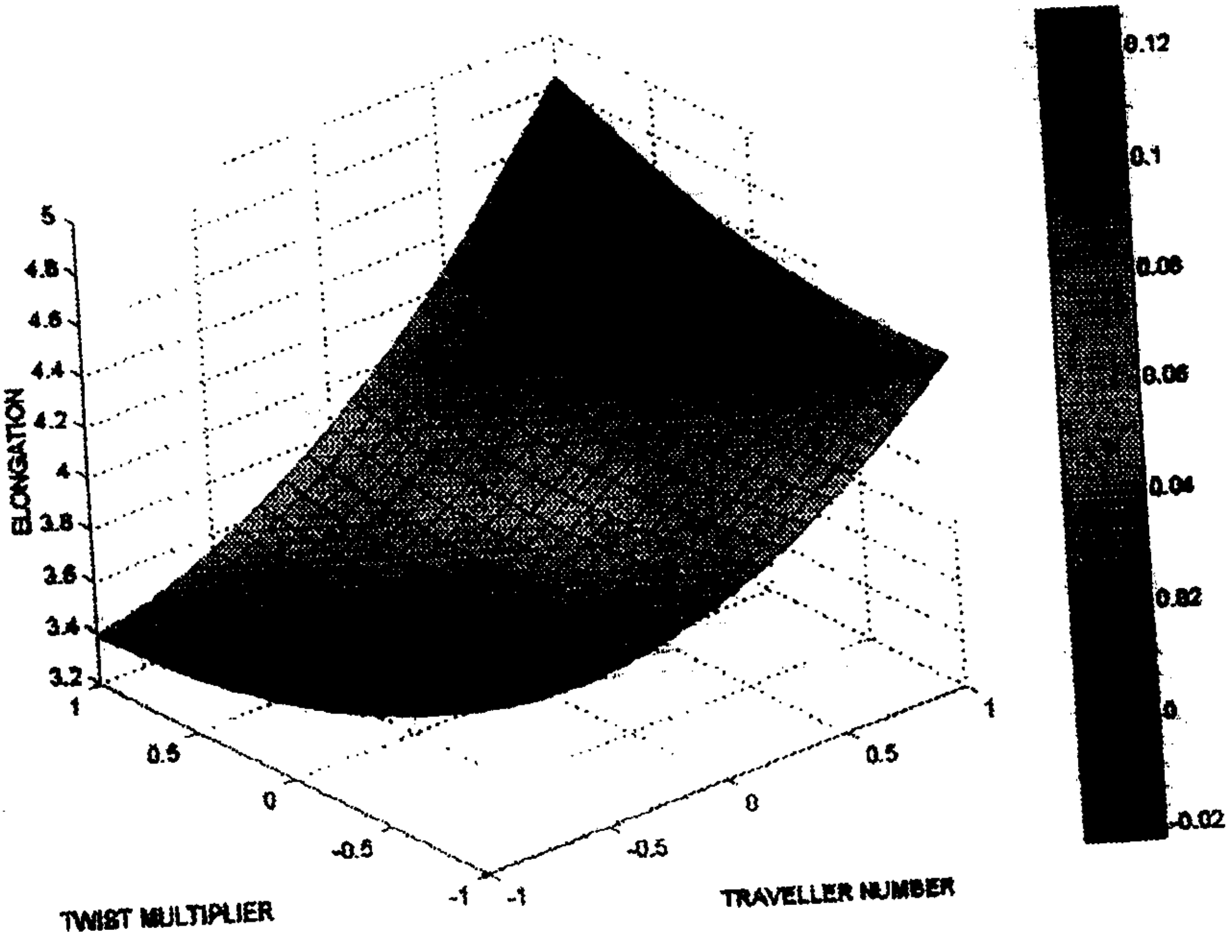
Spindle speed = 14000 rpm



From the graph it can be observed that the yarn elongation decreases sharply with increase in TM from 3.9 to 4.3. There is also a gradual decrease in yarn elongation when the traveler number is varied from 10/O to 14/O. The change in yarn elongation was more marked in the case of varying traveler

Effect of traveler number and Twist multiplier on yarn elongation

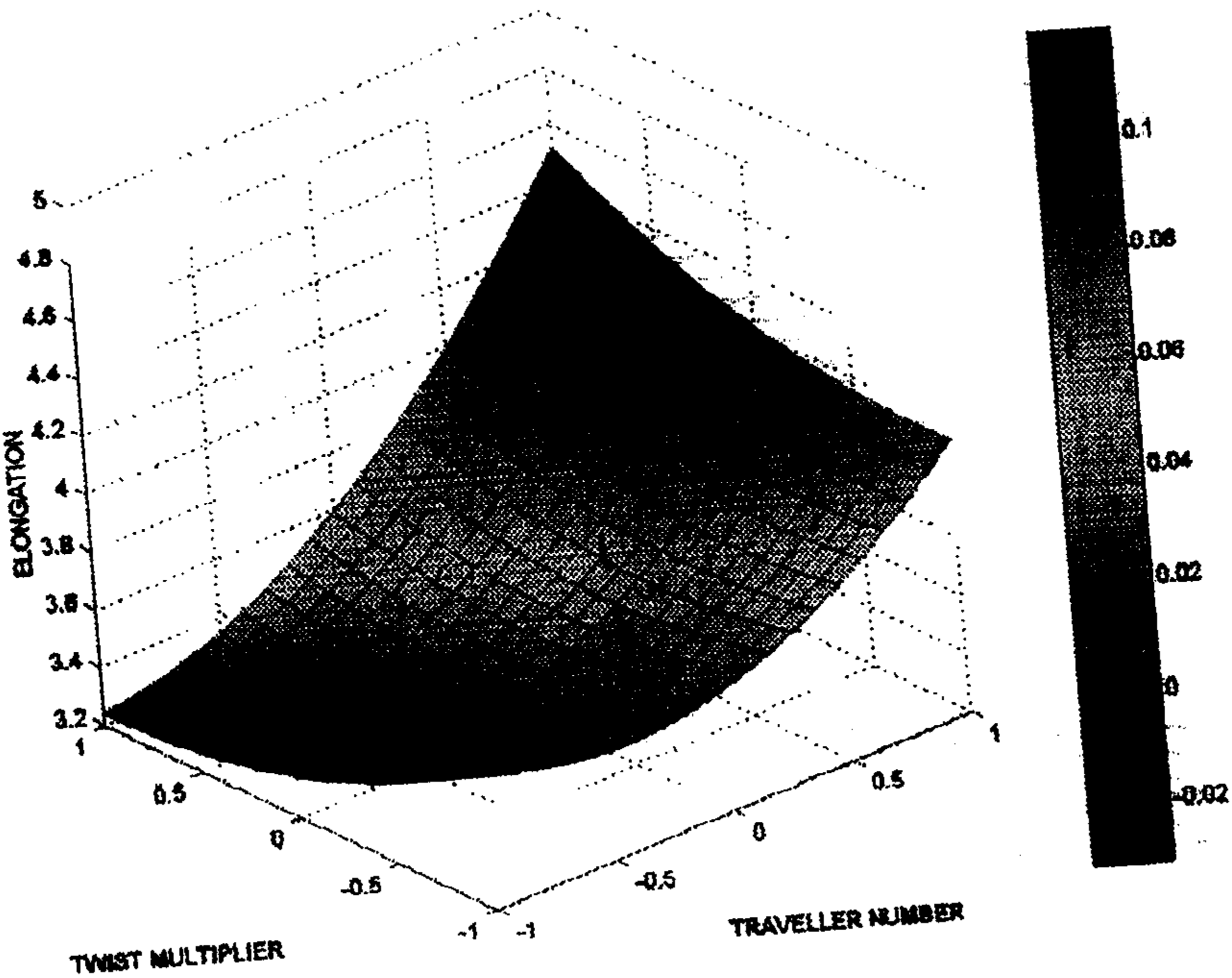
Spindle speed = 15000 rpm



From the graph it can be observed that the yarn elongation decreases sharply with increase in traveler number from 10/O to 14/O and TM values between 3.9 to 4.3. The decrease in the yarn elongation is more prominent with the increase in the traveler number. The effect of traveler number is much more

Effect of traveler number and Twist multiplier on yarn elongation

Spindle speed = 16000 rpm



From the graph it can be observed that the yarn elongation falls with increase in TM from 3.9 to 4.3. On the other hand, yarn elongation gradually decreases with increase in traveler number from 10/O to 14/O. The effect of traveler number is much marked compared to TM.

5.2. Experimental design for three variables (40^s Ne)

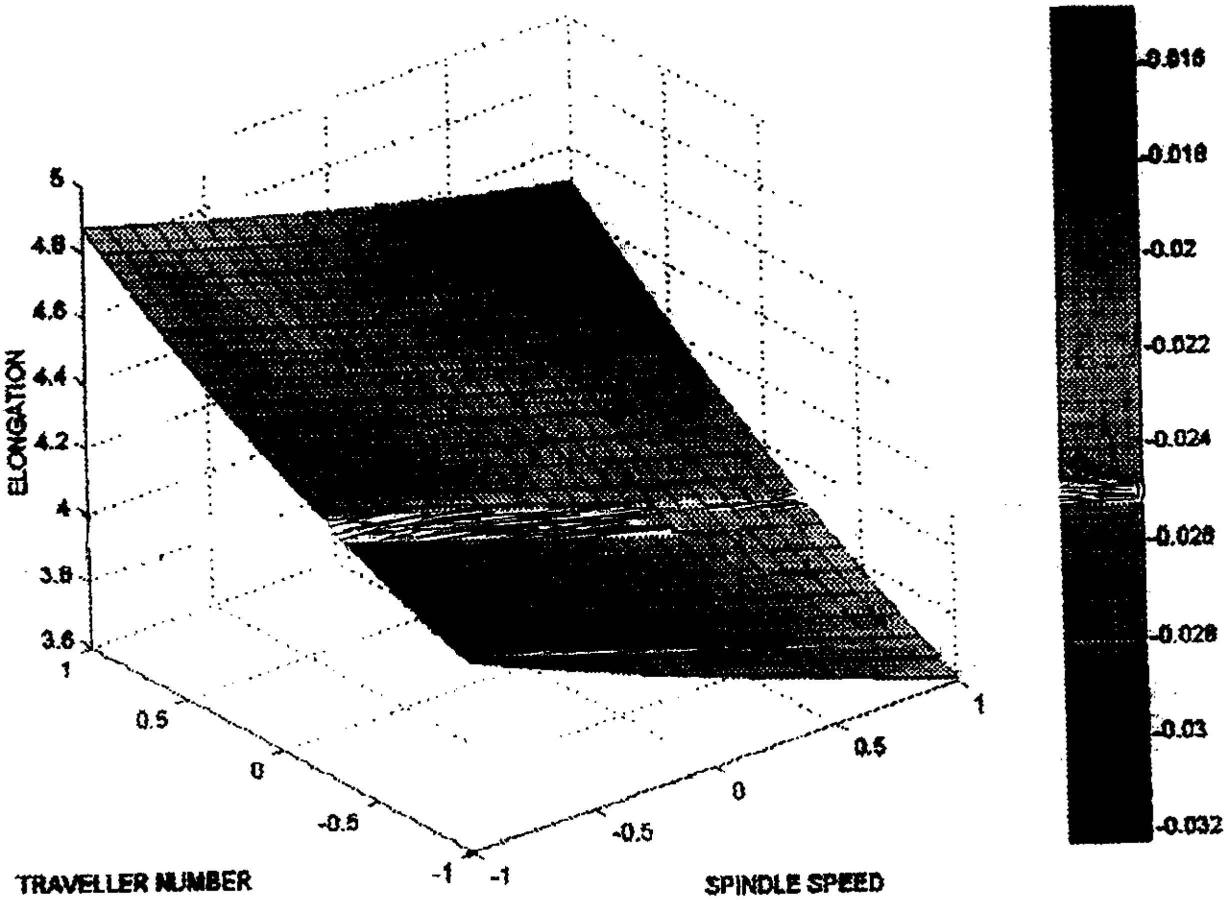
Serial Number	Spindle Speed (rpm)	Traveler Number	Twist Multiplier	Actual Count	Elongation (%)
1.	14000	8/O	4.00	40.25	5.13
2.	16000	8/O	4.00	40.31	4.42
3.	14000	6/O	4.00	41.40	4.67
4.	16000	6/O	4.00	40.88	3.77
5.	14000	7/O	3.75	39.87	4.33
6.	16000	7/O	3.75	41.40	3.95
7.	14000	7/O	4.25	40.01	5.10
8.	16000	7/O	4.25	39.35	4.23
9.	15000	8/O	3.75	40.62	4.65
10.	15000	6/O	3.75	40.86	3.86
11.	15000	8/O	4.25	41.85	4.82
12.	15000	6/O	4.25	40.86	4.49
13.	15000	7/O	4.00	41.85	4.56
14.	15000	7/O	4.00	40.49	4.35
15.	15000	7/O	4.00	40.72	4.30

5.2.1. Regression Equation

$$Y=4.403-0.358A+0.279B+0.231C+0.021A^2+0.073B^2-0.022C^2+0.047AB-0.122AC-0.115BC$$

Effect of spindle speed and traveler number on yarn elongation

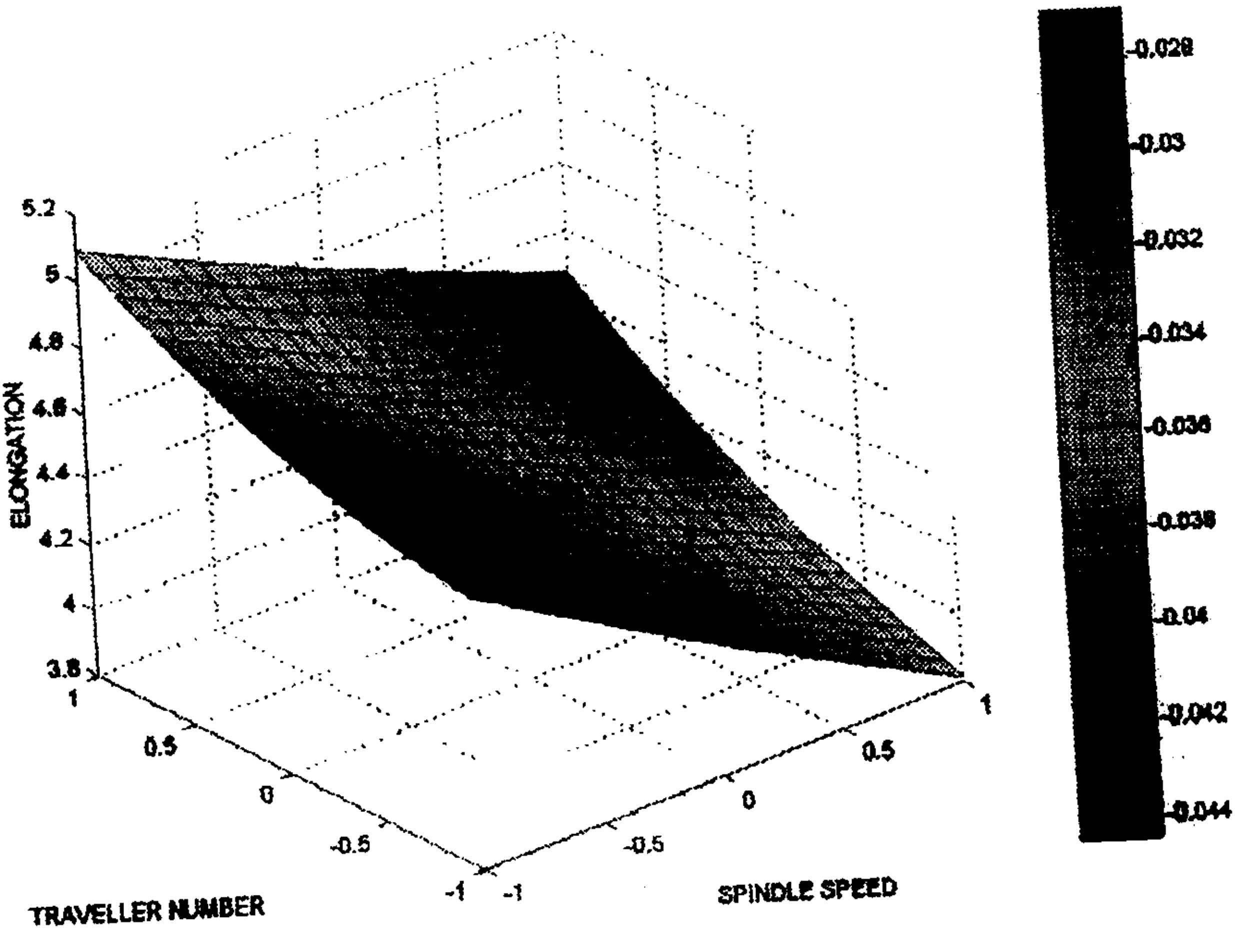
Twist Multiplier = 3.75



It can be observed from the graph that for a given TM value of 3.75, with the increase in the spindle speed from 14000 to 16000 rpm the yarn elongation is found to decrease. Also the yarn elongation value increases with the increase in the traveler number from 6/O to 8/O. This means the yarn elongation increases at lower spindle speeds. The effect of change in spindle speed on yarn elongation is found to be more than that of traveler number.

Effect of spindle speed and traveler number on yarn elongation

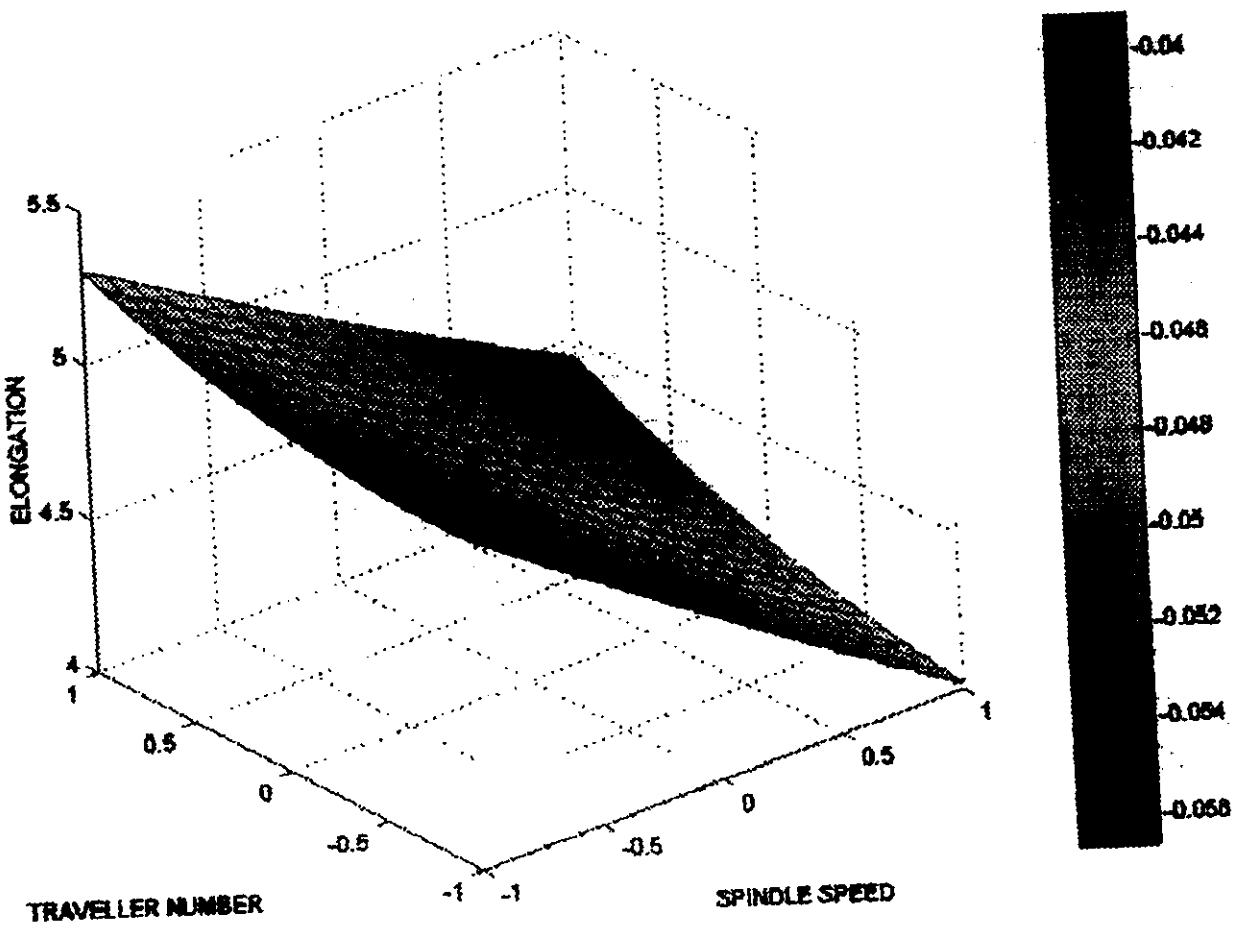
Twist Multiplier = 4.0



At a TM of 4.0, the yarn elongation was found to decrease with increasing spindle speeds from 14000 to 16000 rpm. The yarn elongation was found to increase with increasing traveler number from 6/O to 8/O. At this particular value of TM, the effect of traveler number was found to be lesser than that of spindle

Effect of spindle speed and traveler number on yarn elongation

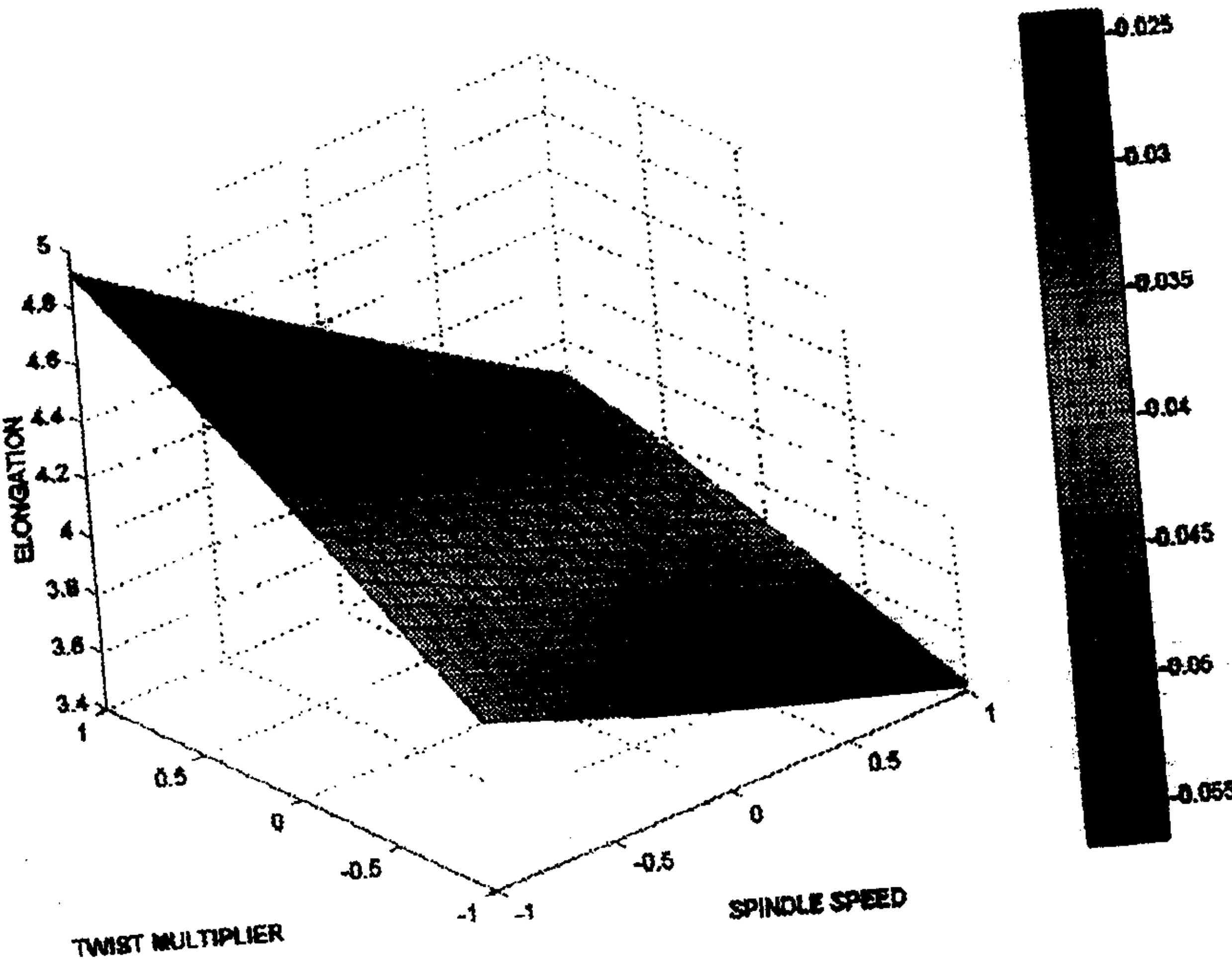
Twist Multiplier = 4.25



As per the graph it can be observed that at a TM value of 4.25, the yarn elongation drastically fell with increasing spindle speed from 14000 to 16000 rpm. The change in traveler number did not show significant change in yarn elongation. Thus it can be seen that the effect of spindle speed at this particular ... pared to traveler number.

Effect of spindle speed and Twist multiplier on yarn elongation

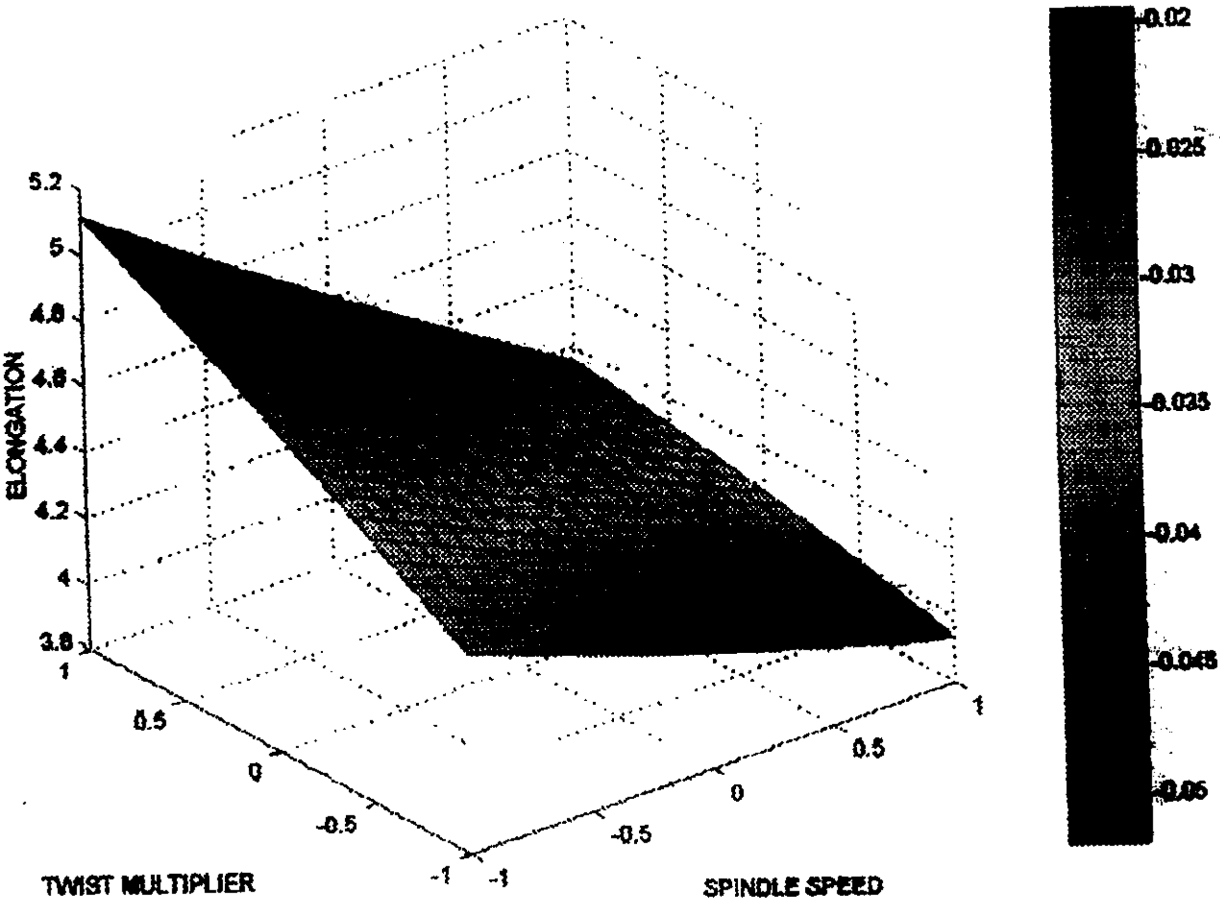
Traveler number = 6/O



The effect of spindle speed and TM at a given traveler size of 6/O can be seen in the graph. It is observed that the yarn elongation value decreased gradually when the spindle speed is increased from 14000 to 16000 rpm. The change in yarn elongation was curvilinear when the TM is increased from 3.75 to 4.25. Thus for a given traveler number, the influence of spindle speed and TM

Effect of spindle speed and Twist multiplier on yarn elongation

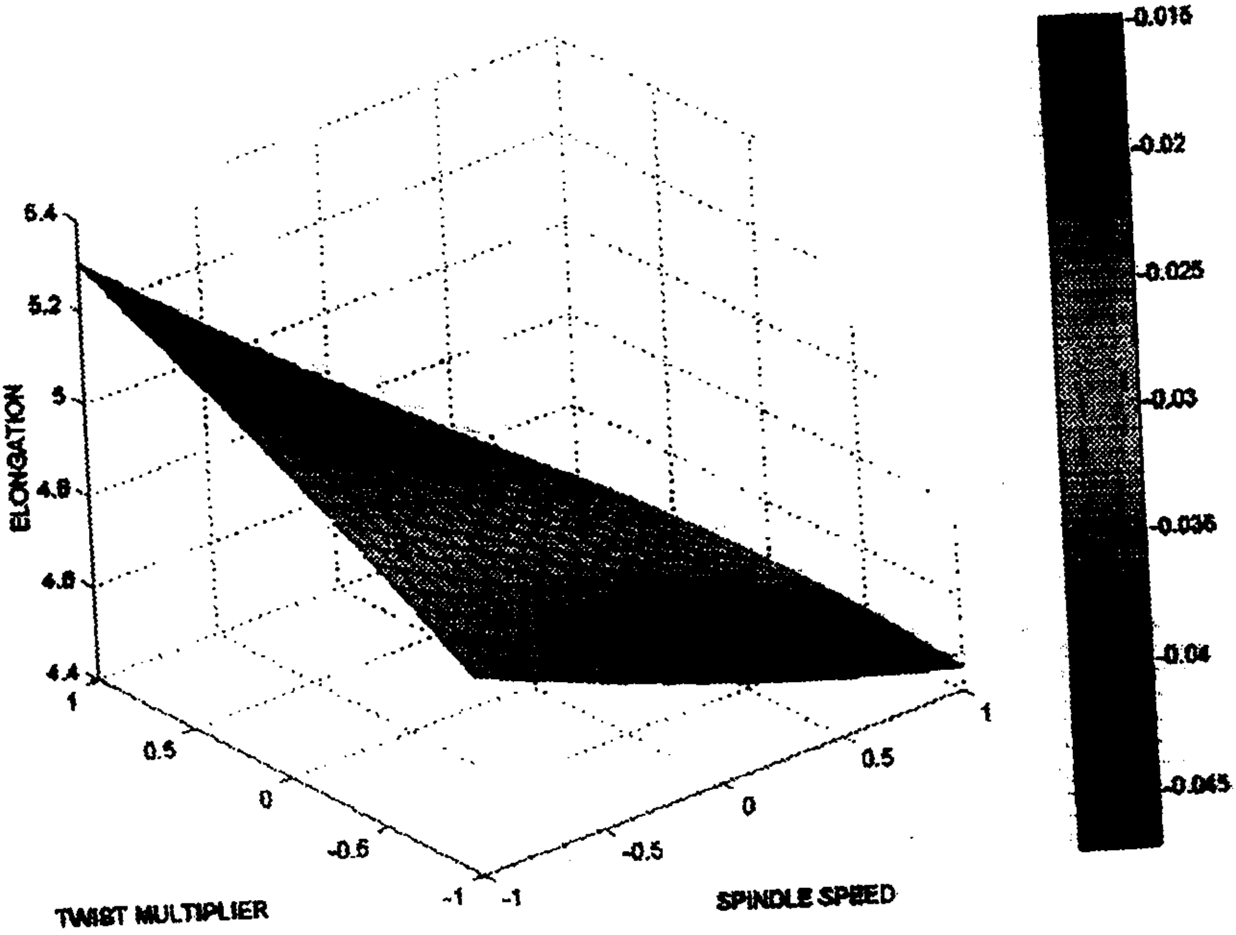
Traveler number = 7/O



The effect of spindle speed and TM at a given traveler size of 7/O can be seen in the graph. It is observed that there is a drastical decrease in yarn elongation when spindle speed is increased from 14000 to 16000 rpm. The yarn elongation steadily increases with change in TM values from 3.75 to 4.25. Thus elongation steadily increases with ... the influence of spindle speed is more pronounced

Effect of spindle speed and Twist multiplier on yarn elongation

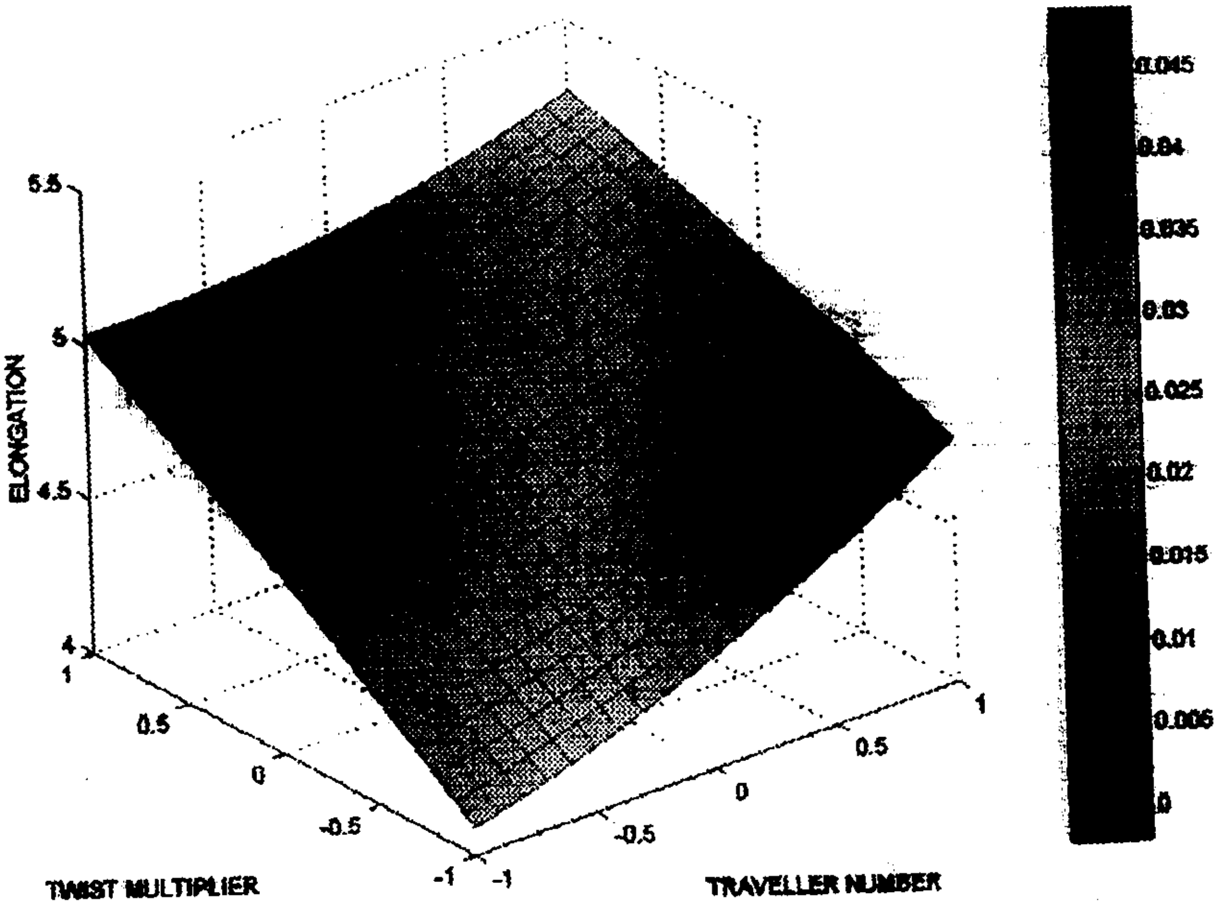
Traveler number = 8/O



As per the graph at a given traveler number of 8/O, the yarn elongation abruptly decrease with increase in spindle speed from 14000 to 16000 rpm. The yarn elongation value increases almost linearly with increase in TM values between 3.75 and 4.25. The effect of spindle speed is much more pronounced

Effect of traveler number and Twist multiplier on yarn elongation

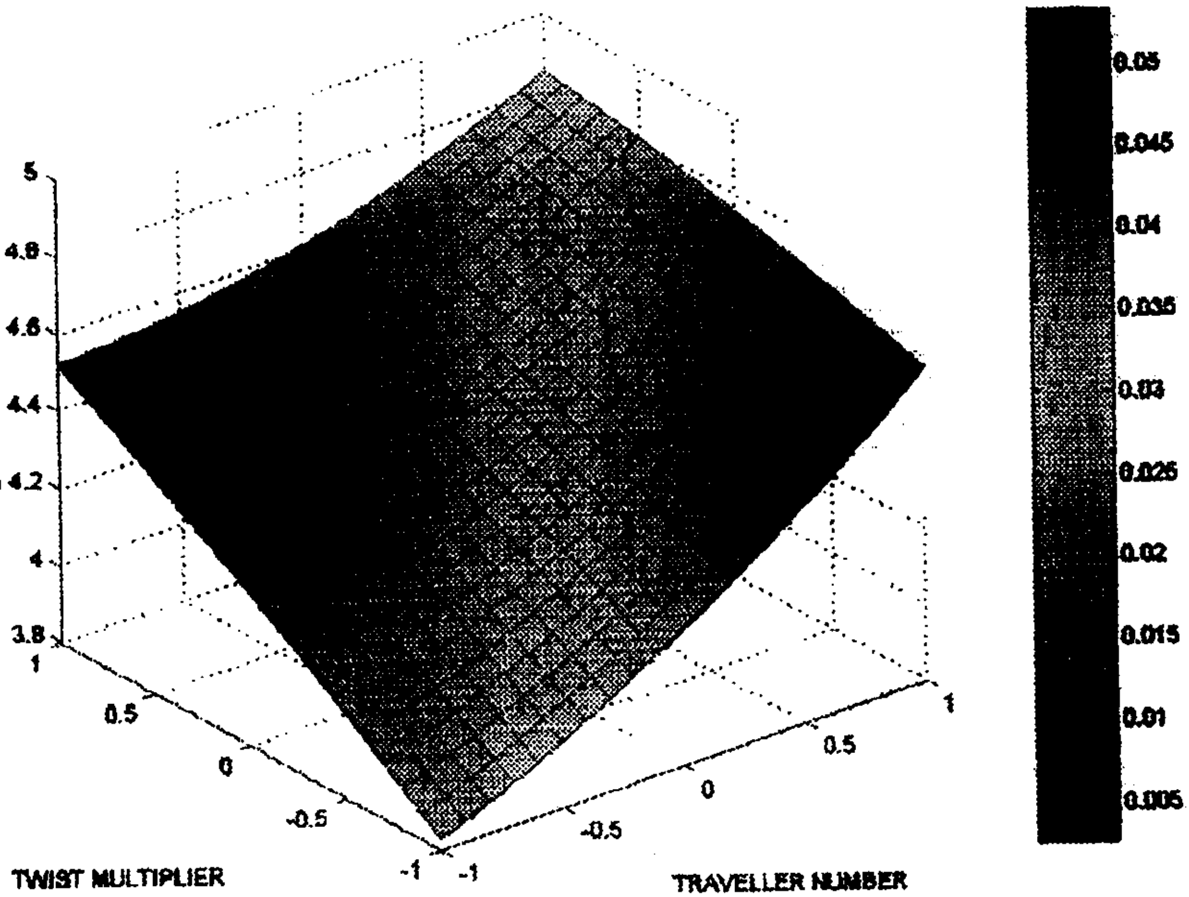
Spindle speed = 14000 rpm



From the graph it can be observed that the yarn elongation increases sharply with increase in TM from 3.75 to 4.25. There is also a gradual increase in yarn elongation when the traveler number is varied from 6/O to 8/O. The change in yarn elongation was more marked in the case of varying traveler number

Effect of traveler number and Twist multiplier on yarn elongation

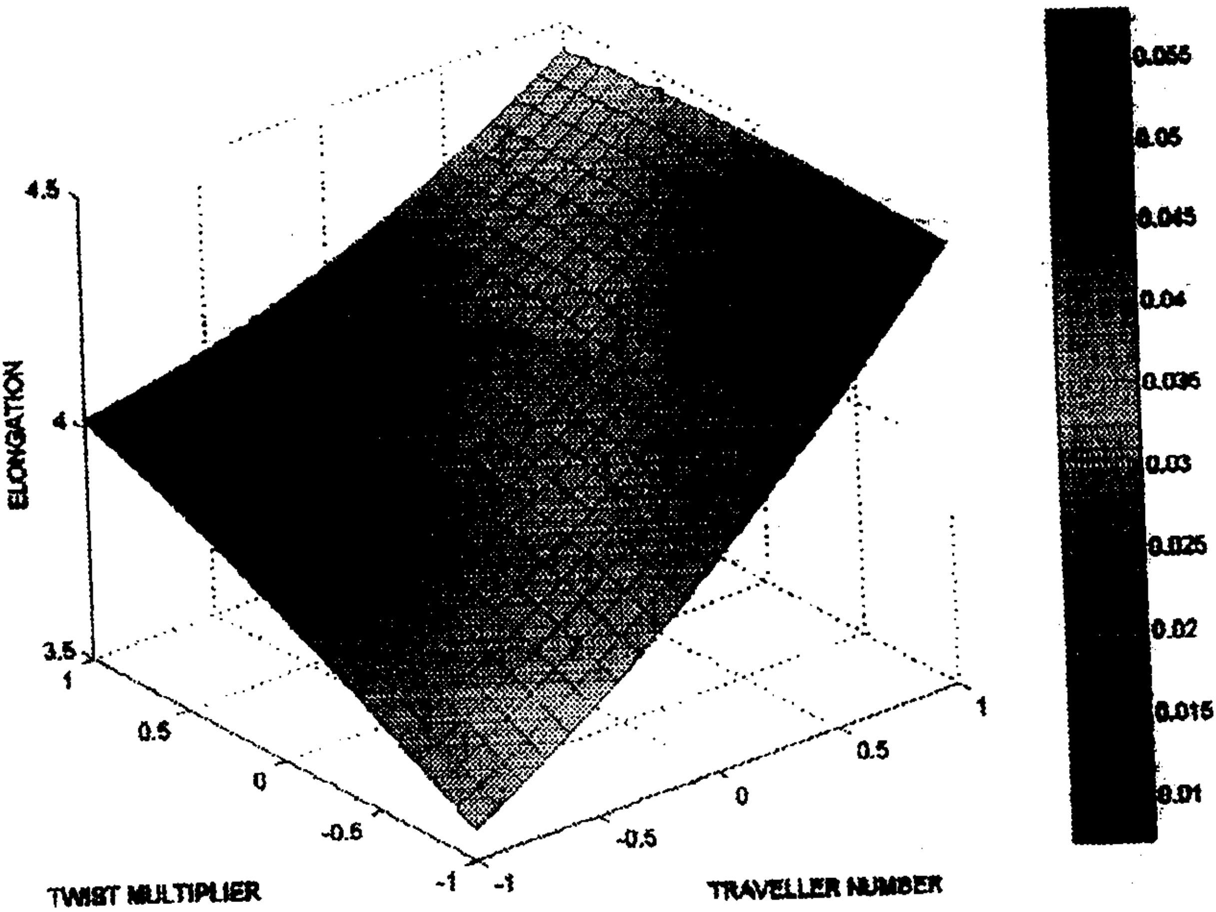
Spindle speed = 15000 rpm



From the graph it can be observed that the yarn elongation increases sharply with increase in traveler number from 6/O to 8/O and TM values between 3.75 to 4.25. The increase in the yarn elongation is more prominent with the increase in the traveler number. The effect of traveler number is much more

Effect of traveler number and Twist multiplier on yarn elongation

Spindle speed = 16000 rpm



From the graph it can be observed that the yarn elongation improves with increase in TM from 3.75 to 4.25. On the other hand, yarn elongation gradually increases with increase in traveler number from 6/O to 8/O. The effect of traveler number is much marked compared to TM.

CHAPTER 6

CONCLUSION

The influence of various spinning parameters such as spindle speed, traveler number and twist multiplier on the yarn elongation has been studied. The effect has been studied by maintaining one parameter constant and varying the other two parameters.

The effect of different spindle speeds by varying traveler number and TM has been studied. It has been found out that with the increase in the spindle speed, the effect of Traveler number was more pronounced than the TM. The elongation increased with increase in the TM and by using lightweight travelers.

The effect of different traveler number by varying spindle speed and TM has been studied. It has been found out that with the increase in the traveler number, the effect of TM was more pronounced than the spindle speed. The elongation increased with decrease in the spindle speed and with increase with the TM.

The effect of different twist multipliers by varying spindle speed and traveler number has been studied. It has been found out that with the increase in the TM, the effect of spindle speed was more pronounced than the traveler number. The elongation increased with decrease in the spindle speed and by using lightweight travelers.

Hence from the above results, we can conclude that the breaking elongation of the yarn increases with decrease in the spindle speed, with increase in the TM and by using lightweight travelers.

CHAPTER 7

APPENDICES

(Annexure-1)

Box-Behnken design

An alternate choice for fitting quadratic models that requires 3 levels of each factor and is rotatable (or "nearly" rotatable)

The Box-Behnken design is an independent quadratic design in that it does not contain an embedded factorial or fractional factorial design. In this design the treatment combinations are at the midpoints of edges of the process space and at the center. These designs are rotatable (or near rotatable) and require 3 levels of each factor. The designs have limited capability for orthogonal blocking compared to the central composite designs.

Box-Behnken design for 3 factors

Geometry of the design

The geometry of this design suggests a sphere within the process space such that the surface of the sphere protrudes through each face with the surface of the sphere tangential to the midpoint of each edge of the space.

Comparisons of response surface designs

Choosing a Response Surface Design

Various CCD designs and Box-Behnken designs are compared and their properties discussed

Table 1 contrasts the structures of four common quadratic designs one might use when investigating three factors. The table combines CCC and CCI designs because they are structurally identical.

For three factors, the Box-Behnken design offers some advantage in requiring a fewer number of runs. For 4 or more factors, this advantage disappears.

Structural comparisons of CCC (CCI), CCF, and Box-Behnken designs for three factors

TABLE 1 Structural Comparisons of CCC (CCI), CCF, and Box-Behnken Designs for Three Factors

CCC (CCI)				**CCF**				**Box-Behnken**			
Rep	***X1***	***X2***	***X3***	**Rep**	***X1***	***X2***	***X3***	**Rep**	***X1***	***X2***	***X3***
1	-1	-1	-1	1	-1	-1	-1	1	-1	-1	0
1	+1	-1	-1	1	+1	-1	-1	1	+1	-1	0
1	-1	+1	-1	1	-1	+1	-1	1	-1	+1	0

1	+1	+1	-1	1	+1	+1	-1	1	+1	+1	0
1	-1	-1	+1	1	-1	-1	+1	1	-1	0	-1
1	+1	-1	+1	1	+1	-1	+1	1	+1	0	-1
1	-1	+1	+1	1	-1	+1	+1	1	-1	0	+1
1	+1	+1	+1	1	+1	+1	+1	1	+1	0	+1
1	-1.682	0	0	1	-1	0	0	1	0	-1	-1
1	1.682	0	0	1	+1	0	0	1	0	+1	-1
1	0	-1.682	0	1	0	-1	0	1	0	-1	+1
1	0	1.682	0	1	0	+1	0	1	0	+1	+1
1	0	0	-1.682	1	0	0	-1	3	0	0	0
1	0	0	1.682	1	0	0	+1				
6	0	0	0	6	0	0	0				
Total Runs = 20				**Total Runs = 20**				**Total Runs = 15**			

Factor settings for CCC and CCI three factor designs

Table 2 illustrates the factor settings required for a central composite circumscribed (CCC) design and for a central composite inscribed (CCI) design (standard order), assuming three factors, each with low and high settings of 10 and 20, respectively. Because the CCC design generates new extremes for all factors, the investigator must inspect any worksheet generated for such a design to make certain that the factor settings called for are reasonable.

In Table 2, treatments 1 to 8 in each case are the factorial points in the design; treatments 9 to 14 are the star points; and 15 to 20 are the system-recommended center points. Notice in the CCC design how the low and high values of each factor have been extended to create the star points. In the CCI design, the specified low and high values become the star points, and the system computes appropriate settings for the factorial part of the design inside those boundaries.

TABLE 2 Factor Settings for CCC and CCI Designs for Central Composite

Sequence	***X*1**	***X*2**	***X*3**		**Sequence**	***X*1**	***X*2**	***X*3**
1	10	10	10		**1**	12	12	12
2	20	10	10		**2**	18	12	12
3	10	20	10		**3**	12	18	12
4	20	20	10		**4**	18	18	12
5	10	10	20		**5**	12	12	18
6	20	10	20		**6**	18	12	18
7	10	20	20		**7**	12	12	18
8	20	20	20		**8**	18	18	18
9	6.6	15	15	*	**9**	10	15	15
10	23.4	15	15	*	**10**	20	15	15
11	15	6.6	15	*	**11**	15	10	15
12	15	23.4	15	*	**12**	15	20	15
13	15	15	6.6	*	**13**	15	15	10
14	15	15	23.4	*	**14**	15	15	20
15	15	15	15		**15**	15	15	15
16	15	15	15		**16**	15	15	15

16	15	15	15		**16**	15	15	15
17	15	15	15		**17**	15	15	15
18	15	15	15		**18**	15	15	15
19	15	15	15		**19**	15	15	15
20	15	15	15		**20**	15	15	15

* are star points

Factor settings for CCF and Box-Behnken three factor designs

Table 3 illustrates the factor settings for the corresponding central composite face-centered (CCF) and Box-Behnken designs. Note that each of these designs provides three levels for each factor and that the Box-Behnken design requires fewer runs in the three-factor case.

TABLE 3 Factor Settings for CCF and Box-Behnken								
Central Composite					**Box-Behnken**			
Sequence	***X1***	***X2***	***X3***		**Sequence**	***X1***	***X2***	***X3***
1	10	10	10		**1**	10	10	10
2	20	10	10		**2**	20	10	15
3	10	20	10		**3**	10	20	15
4	20	20	10		**4**	20	20	15
5	10	10	20		**5**	10	15	10
6	20	10	20		**6**	20	15	10
7	10	20	20		**7**	10	15	20
8	20	20	20		**8**	20	15	20
9	10	15	15	*	**9**	15	10	10
10	20	15	15	*	**10**	15	20	10

10	20	15	15	*	**10**	15	20	10
11	15	10	15	*	**11**	15	10	20
12	15	20	15	*	**12**	15	20	20
13	15	15	10	*	**13**	15	15	15
14	15	15	20	*	**14**	15	15	15
15	15	15	15		**15**	15	15	15
16	15	15	15					
17	15	15	15					
18	15	15	15					
19	15	15	15					
20	15	15	15					

* are star points for the CCC

Properties of classical response surface designs

Table 4 summarizes properties of the classical quadratic designs. Use this table for broad guidelines when attempting to choose from among available designs.

TABLE 4 Summary of Properties of Classical Response Surface Designs

Design Type	Comment
CCC	CCC designs provide high quality predictions over the entire design space, but require factor settings outside the range of the factors in the factorial part. **Note:**

	(reasonable) levels. Requires 5 levels for each factor.
CCI	CCI designs use only points within the factor ranges originally specified, but do not provide the same high quality prediction over the entire space compared to the CCC. Requires 5 levels of each factor.
CCF	CCF designs provide relatively high quality predictions over the entire design space and do not require using points outside the original factor range. However, they give poor precision for estimating pure quadratic coefficients. Requires 3 levels for each factor.
Box-Behnken	These designs require fewer treatment combinations than a central composite design in cases involving 3 or 4 factors. The Box-Behnken design is rotatable (or nearly so) but it contains regions of poor prediction quality like the CCI. Its "missing corners" may be useful when the experimenter should avoid combined factor extremes. This property prevents a potential loss of data in those cases. Requires 3 levels for each factor.

Number of runs required by central composite and Box-Behnken designs

Table 5 compares the number of runs required for a given number of factors for various Central Composite and Box-Behnken designs.

TABLE 5 Number of Runs Required by Central Composite and Box-Behnken Designs

Number of Factors	Central Composite	Box-Behnken
2	13 (5 center points)	-
3	20 (6 centerpoint runs)	15
4	30 (6 centerpoint runs)	27
5	33 (fractional factorial) or 52 (full factorial)	46
6	54 (fractional factorial) or 91 (full factorial)	54

CHAPTER 8

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