Regressional Optimizations of Cotton Spun Yarn by Controlling its Process Parameters

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Abstract

Cotton is the most commonly used natural fiber and has a significant contribution to the production of yarn manufacturing. This yarn is subsequently utilized for the production of fabrics, garments, and other textile products. The quality of the end product depends on the selection of an appropriate spinning process and output parameters. Numerous methods and processes are involved in the production of yarn. Ring spinning machine is most commonly used for the production of cotton spun yarn. It is necessary to optimize the process parameters of ring-spun yarn without compromising on quality and production. In this research work; these parameters have been optimized by applying the multiple linear regression analysis. The process parameters (especially spindle speed, twist and yarn diameter) and their effect on yarn quality have been discussed in detail. Total 135 ring-spun yarn samples have been produced under three different levels of spindle speed, twist, and linear density. These yarn samples are categorized as 8 Ne, 16 Ne, and 24 Ne at three different Twist multipliers (3.8, 4.0, and 4.2) and different revolutions per minute of the spindle (9500 rpm, 10500rpm, and 11500 rpm).

The models have been designed to predict the quality of ring-spun by utilizing USTER evenness tester data. The Count of yarn, yarn twist, and spindle speed were selected as a predictor. The multiple regression method has been used to find out the relation between the process parameters and yarn quality characteristics. The high values of R^2 (the coefficient of determination) showed the relationships in the prediction model.

Introduction

Cotton is composed of vegetable fiber with many desired physical characteristics like strength, good comfort, and dye pick-up ability, due to this, it is suitable for making a wide range of textile goods. Approximately 50–56% of the clothing and household market portion is taken by cotton. Moreover, cotton is also widely used in the non-woven industry for the manufacturing of textiles and unique protective articles, which are preferred by consumers.

Ring spinning is widely used amongst the other spinning machines in Pakistan because it exhibits significant advantages in comparison with the new spinning systems. In the last century, several types of yarn production have been introduced and designed for cotton yarn spinning, however, ring spinning has not been replaced by anyone because of firm control of the cotton yarn quality parameters that can be optimized on ring spinning. These parameters not only affect the weaving process but also in dyeing and printing process [1].

The annual production of cotton is approximately 100 million bales around the world. The Cotton production is nearly about 117 million bales recorded in the years 2006 and 2007 [1]. The yarn manufacturers are in need to produce the quality of yarn for the market. For the production of quality yarn, it is necessary to check and test the cotton properties properly. Earlier the cotton was not tested due to which the quality of the textile yarn and fabric suffered. In the era of 80s and 90s, research has been done and investigated that cotton testing is the fundamental compulsion to get the best quality product.

Cotton has versatile properties that are comfort, disability, and absorbency, etc. These qualities depend upon the selection of the cotton fiber used for the production of the desired product[2, 3]. The cotton fiber characteristics are directly related to the yarn properties. The appropriate cotton fiber selection results in the yarn quality, whereas end-use properties are controlled through the raw material selection [4]. Cotton is used as a garment for decades due to its social and cultural adaptability and medical compatibility. Due to the molecular structure, it has excellent absorbency properties. In the apparel industry, about 66% of cotton is consumed worldwide. [5].

The quality of the product has a significant role in the sustainability of the product in the market. The quality of textile products has had a notable role in recent decades. To produce the quality cotton spun yarn, it is necessary to select the appropriate raw cotton and machine process parameters settings; otherwise, the producer could face deterioration in the quality and machine performance. There exists a direct and indirect relationship between the production process parameters with the physical and mechanical properties of cotton yarn (evenness, hairiness, strength, imperfection, tenacity, work of rapture, elongation, lea strength product (bulk strength) [1, 6, 7].

There is an effect of delivery speed and count of yarn upon the yarn properties produced among numerous factors during the spinning process. The study results show that the spindle speed of the ring machine and yarn count substantially affect the evenness, hairiness, IPI, and strength of the yarn. I am increasing the front roller speed resulting in the increase of yarn hairiness and a decrease in the strength and neps of threads [8]. A study of three different yarn spinning techniques by Kumar, Salhotra, and Ishtiaque in 2006, describes that the ring-spinning system has better yarn evenness and tensile properties compared to the other spinning systems [9].

The process involves the manufacturing of the ring spinning yarn affecting the hairiness, strength, and yarn imperfection of the yarn. The primary role of the process machines like drawing frame, simplex, and ring in the yarn quality entirely dominated the machine roller setting that controls the fibers diameters and the fiber friction [10]. The strength of the cotton ring-spun yarn depends upon the strength of the cotton fiber. Besides that the twist of yarn has a significant role in the strength properties because of the compactness of fiber and resulting in high tensile properties [11], the abrasion resistance, strength, and the smooth appearance of the cotton fabric are dependent on the diameter of the yarn, i.e., the cotton yarn count. Finer will be the count resulting more seamless look and impart comfortable feel in woven fabrics [12]. The spindle speed has a direct relation with the hairiness of the ring spinning yarn which also has a noticeable effect on the yarn end breakage rate which affects the production efficiency as studied by the Xungai Wang1 in 2006 [13].

The study of process parameters in 2005 shows that the parameters like ring spindle speed, roving, and yarn twist have directly and indirectly affected the yarn hairiness and imperfections [14]. The comfort of the cotton-woven fabrics depends on the process parameters. The spindle speed and yarn twist multiplier are directly related to the hairiness, air permeability, and absorbency of cotton fabric as investigated by G K Tyagi in 2009 [15].

At present, almost all the cotton bales have been tested not only in the United States but also in other quality yarn-producing countries around the globe. The raw material has nearly 50 percent of the total cost of the end product. Cotton fibers are firstly arranged into different groups for classification. It is done manually by sorting the material based on the area of cultivation. Unusual specimens taken from the different cotton lots and bales determine the cotton quality, which is randomly tested by using various testing instruments [16].

In this research work, the essential physical properties of spun cotton yarn were studied and investigated its relationship with production process parameters. For the optimization of spun cotton yarn, the precise evaluation of the production process was investigated at (different count, twist, and production rate) and correlated each property with a quality parameter of the yarn. The multiple regression models were applied to predict the physical properties of ring-spun yarn as a spinner (producer) can easily optimize the required cotton yarn result before the complete spinning process.

Materials And Methods

Materials and experimental work

The current cotton crop of Pakistan was used as infeed material to the ring-spinning machine. The hank of roving was 0.86 Ne was used as an input package for the production of ring-spun yarn samples. The roving frame FL-16 was used to produce 5~6 roving bobbins. All ring-spun yarn samples were spun on the ring frame Toyoda Rx-240. The three different yarn counts of $8^{s,}$ $16^{s,}$ and 24^{s} were produced. Every single carded yarn count was spun at different twist multiplier (8^{s} at 3.45, 3.8, and 4.0), (16^{s} at 3.8, 4.2, and 4.6) and (24^{s} at 4.2, 4.6, and 4.9) at three different spindle speeds (8^{s} at 9500, 10500 and 11500 rpm), (16s at 10500, 13500 and 16000 rpm) and (24^{s} at 10500, 13500 and 16000 rpm). A total of 135 samples were produced for testing and prediction model.

Testing method

The yarn parameters analyses tests, evenness, CV (coefficient of variation), number of faults (Thin-50%, Thick+50%, and Neps +200%,), yarn density, and yarn diameter were tested on Uster Tester 5. The moisture content and relative humidity affect the properties of the yarn. It also affects the structure of the cotton yarn and induces changes in the diameter of the thread. All samples were tested in an isolated laboratory where the standard temperature and humidity were 20 ± 2°C and R.H 65 ± 2% [17].

Statistical method

Regression analysis is the most commonly used statistical technique for establishing the relationship between the dependent and independent variables. The advantage of this regression method is to simplify and describe the quantitative relation between cotton yarn properties. In practice; multiple linear regression analysis was used to establish the relationship between the process and the yarn quality parameters. Firstly, the type of connection between the independent variable (process parameters) and dependent variable (yarn properties) was analyzed independently by applying the linear line correlation analysis. It was found that a linear relationship exists between the process parameters and features of the yarn. Therefore, the multiple linear regression method was selected for this research work.

Results And Discussion

Regression analysis of U% versus count, twist multiplier, and spindle speed

The effect of variation of the count, spindle speed rpm, and twist multiplier was analyzed by applying the multiple regression models in mini tab software. The tabulated values in the columns indicate the effect of each variable with the corresponding yarn unevenness.

The multiple linear regression analysis of the three different variables with the yarn unevenness percentage is given in Table 1.

The three R-square values show their correlation significance. Each coefficient of the variables indicates the change in mean response standard error coefficient SE is positive, and the smaller amount means the precise estimation. The t-value is calculated by dividing the coefficient by its standard error. The T-value differs from zero, note that the coefficient is significant.

Table 1
Value of dependent (U %) and independent variables

S.No	U (%)	Count (Ne)	T.M	spindle speed(rpm)
1	11.074	7.942	3.45	9500
2	11.084	8.03	3.45	10500
3	11.49	8.092	3.41	11500
4	11.198	7.86	3.78	9500
5	11.272	7.81	3.86	10500
6	11.274	7.892	3.81	11500
7	11.45	7.846	4.17	9500
8	11.192	7.834	4.09	10500
9	11.234	7.804	4.03	11500
10	11.238	15.786	3.79	10500
11	13.256	15.84	3.93	13500
12	13.288	16.116	3.69	16500
13	12.764	15.626	4.23	10500
14	12.994	15.834	4.14	13500
15	13.21	16.106	4.18	16500
16	12.648	15.416	4.68	10500
17	13.066	15.618	4.67	13500
18	13.18822	15.992	4.59	16500
19	14.364	23.67	4.33	10500
20	14.064	23.982	4.24	13500
21	14.502	23.794	4.23	16500
22	13.948	23.644	4.6	10500
23	13.952	24.006	4.61	13500
24	14.266	24.574	4.54	16500
25	14.144	23.362	4.98	10500
26	14.452	23.822	5.07	13500
27	14.22	24.704	4.85	16500

The P- the value of the coefficients less than 0.05 indicates its statistically considerable relationship between predictors and its response. The surface plot graph of U% verse spindle speed rpm and count shows the effect of ring frame spindle speed and twist multiplier of yarn on the irregularity of the yarn.

Figures 1 and 2 show surface plots of U% against twist multiplier and count, it can be calculated that the yarn irregularity decreased with the increase of yarn twist. However, initially increase in spindle speed irregularity decreased, but if it is more increased in spindle speed, it increased. In 2015 Sanghita Basu, developed the relationship between spindle speed, count, and the yarn irregularity percentage [14]. When the count and spindle speed of the yarn was on the higher side, then the U% of the yarn was increased.

The same trend was observed when the same graph compared between the U% verse count and T.M. It means the increase in production rate and twist results also to yarn unevenness.

Equation 1: *Multiple Regression equation of U %*

$$U\% = 7.981 + 0.1519\ Count + 0.307\ T.M + 0.000087\ spindle\ speed$$

Figure 3 and 4 presents counter plot U% against twist multiplier and count. The multiple linear regression analysis, the high value of R^2, adjusted $R^{2,}$ and predicted R^2 show that there is a significant relation between U%, T.M, and the count of the yarn. The high amount of the predicted R^2 indicates that the predictor is more meaningful because of their low p-value. The R^2 value of 93.64% shows that U % is highly affected by all of the three variables. The entire regression coefficients in the model are significant statistically. Equation 1 indicates that U% of yarn increase with the increase of yarn count fineness, twist constant, and spindle speed rpm.

Regression Analysis of imperfection index

The multiple linear regression analysis of yarn imperfection index (IPI) and its correlation with the count value twist multiplier and spindle speed.

The values of the regression model for U% are given in Table 2 and graphs, predicted equation, and its model are illustrated below.

Table 2
Value of dependent (U %) and independent variables

Value Term	**Co-efficient**	**SE Co-efficient**	**Value of T**	**Value of P**	**R^2**	**R^2 (adjust)**	**R^2 (pred)**
Constant	7.981	0.835	9.56	0.000	93.64%	92.81%	91.15%
Count	0.1519	0.0165	9.18	0.00			
T.M	0.307	0.215	1.43	0.166			
Spindle speed	0.000087	0.000031	2.77	0.011			

Table 3
Values of dependent variable (IPI) and independent variables

S.no	IPI	Count (Ne)	T.M	Spindle speed (RPM)
1	82.5	7.942	3.45	9500
2	81.5	8.03	3.45	10500
3	118.14	8.092	3.41	11500
4	93	7.86	3.78	9500
5	97	7.81	3.86	10500
6	105.5	7.892	3.81	11500
7	84.5	7.846	4.17	9500
8	95	7.834	4.09	10500
9	95	7.804	4.03	11500
10	477.5	15.786	3.79	10500
11	540.5	15.84	3.93	13500
12	563	16.116	3.69	16500
13	457	15.626	4.23	10500
14	472	15.834	4.14	13500
15	474.5	16.106	4.18	16500
16	437.5	15.416	4.68	10500
17	521.5	15.618	4.67	13500
18	442.5	15.992	4.59	16500
19	1060.5	23.67	4.33	10500
20	956.5	23.982	4.24	13500
21	1025.5	23.794	4.23	16500
22	857.5	23.644	4.6	10500
23	930.5	24.006	4.61	13500
24	963	24.574	4.54	16500
25	972.5	23.362	4.98	10500
26	973.16	23.822	5.07	13500
27	1025.5	24.704	4.85	16500

Table 4
Regression model summary of IPI

Value Term	Co-efficient	SE Co-efficient	Value of T	Value of P	R^2	R^2 (adjust)	R^2 (pred)
Constant	-229	114	-2.01	0.057	98.54%	98.35%	97.83%
Count	56.72	2.26	25.10	0.00			
T.M	-29.3	2.26	-1.00	0.328			
Spindle speed	-0.00242	0.00428	-0.57	0.577			

Table 3 presents the values of the dependent variable (IPI) and independent variables, and Table 4 show the regression model summary of IPI. The imperfection indexes IPI are the yarn faults in the form of thick, thin, and neps. This imperfection affects the external appearance of yarn and produced strong and weak points on the yarn [18]. The imperfections are increased by increasing the production rate of the yarn on the ring frame, which is due to the extensive rubbing action between the surface of the thread, balloon control ring, travelers, and the ring itself [14].

In general, the yarn imperfection index is found to increase with the increase of yarn count, while the higher twist factor led to the high yarn imperfections except in the case of slow spindle speed. Meanwhile, the twist factor has a different sign in the regression equation of cotton yarns shows its opposite effect — effects of variables on yarn imperfection.

Figures 5 and 6 show counterplot against spindle speed and count whereas; Figures 7 and 8 present counterplots against twist multiplier and count. It is demonstrated that yarn of fault increases with the increase of twist factor, yarn fineness.

It is noted from the observation of the experiment that the effects of twist multiplier on yarn imperfection are opposite. These results show that the increase of the yarn twist factor will lower the fault at the same spindle speed. While at high spindle speed on different twist factors will increase the yarn imperfections.

Equation 2: *Multiple regression equation of IPI*

$$IPI = -229 + 56.72\ Count - 29.3\ T.M - 0.00242\ spindle\ speed$$

The Regression equation shows that there is a direct relation of count and the indirect relationship of the twist multiplier and spindle speed with yarn imperfections. The high value of R^2 square indicates that there is a very significant relation of yarn imperfection with all the other variables.

Conclusions

In this research work; yarn physical parameters have been measured and optimized by relating the multiple linear regression analysis. The process factors (especially spindle speed, twist and yarn diameter) and their effect on yarn quality have been discussed in detail. The typical conclusions are given as under;

1. The relationship between yarn properties (dependent variable) with the process parameters (independent variables) is related to each other. The experimental research analysis showed that there was a notable effect of the spinning process parameters such as spindle speed, yarn twist multiplier, and yarn count on the properties of yarn like yarn irregularity and yarn imperfection.
2. The optimal variable are achieved from this work are spindle speed (10500 to 16500) rpm, yarn TM (3.45 to 4.9), and yarn count (8, 16, and 24). We have found that the most appropriate values at a spindle speed of 11500 rpm for 16/s, Twist multiplier of 4.9 in the case of 24/s, and Twist multiplier of 3.8 in the case of 8/s, respectively.

Declarations

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Autors Constributions

Muhammad Ali Zeeshan composed the data; Zamir Ahmed Abro drafted the manuscript, edited Abdul Malik Rehan the manuscript, and reviewed sentence structure, Ahmer Hussain Shah, Nazakat Ali Khoso, and Syed Qutaba bin Tariq read and ratified the final version.

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Availbilty of data and Material

All materials and data collection was succesfully received from Textile Testing Lab.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

There is no conflict of interest, and this work was not harmful to society and animals.

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Figures

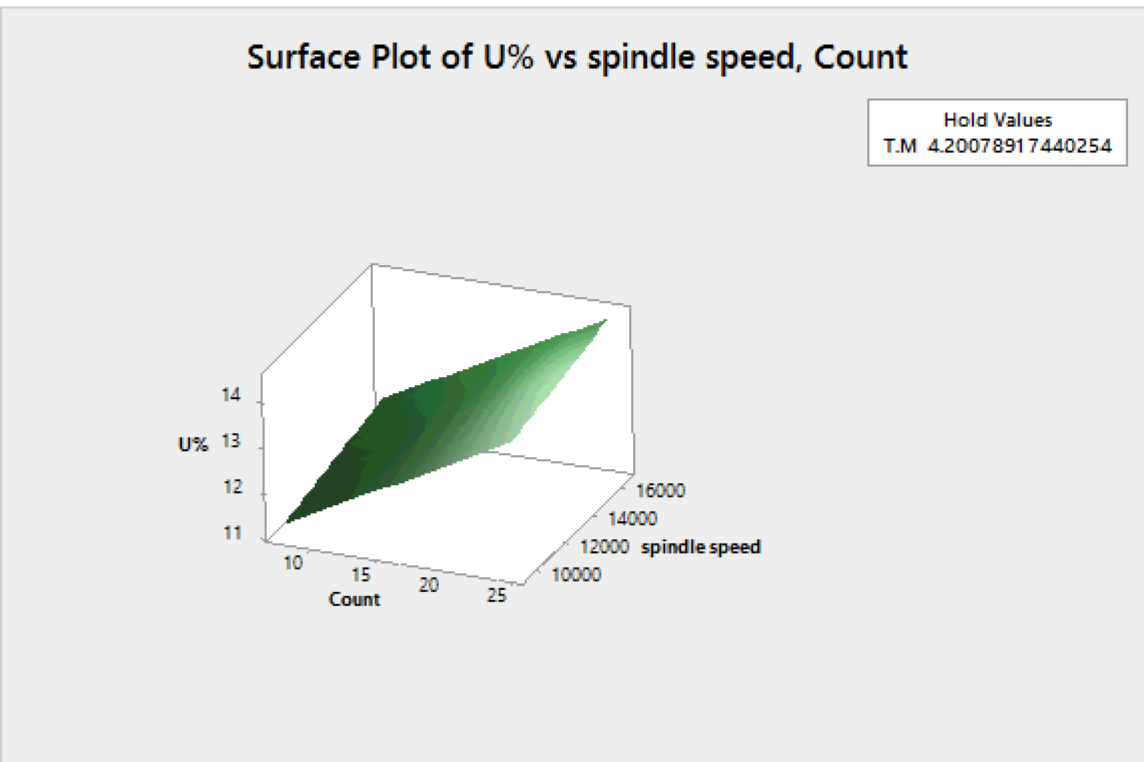

Figure 1

Surface plot U% against spindle speed and count

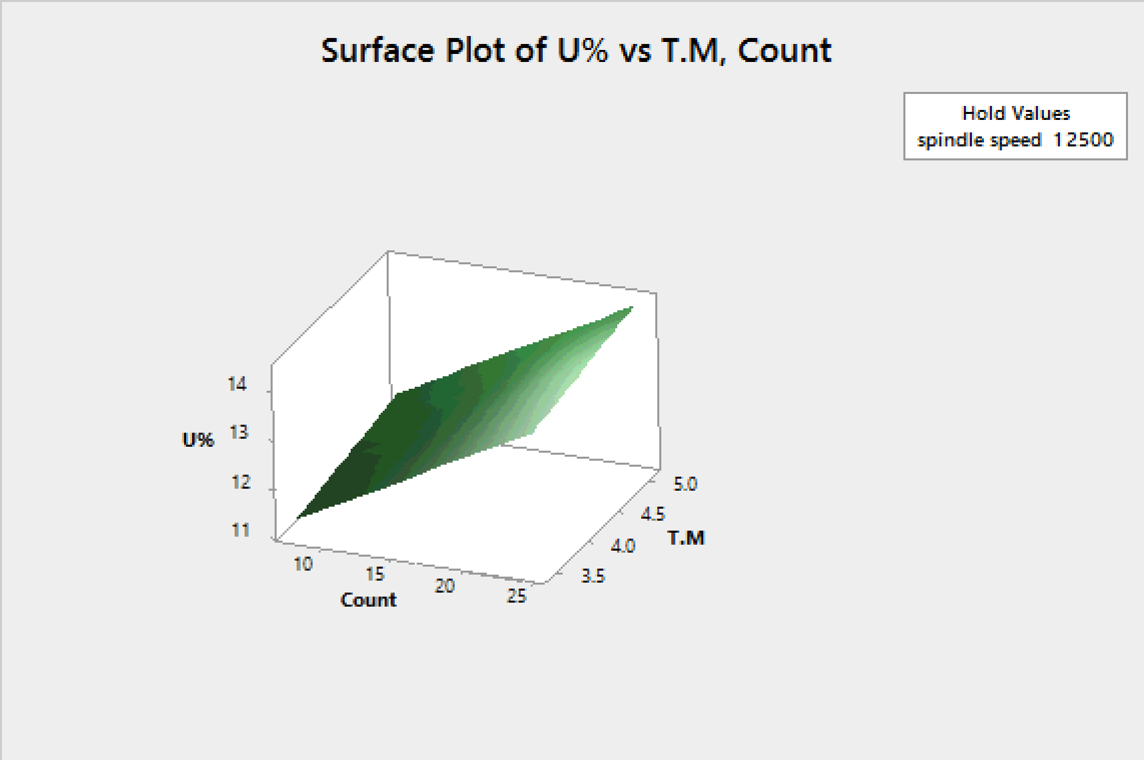

Figure 2

Surface plot U% against twist multiplier and count

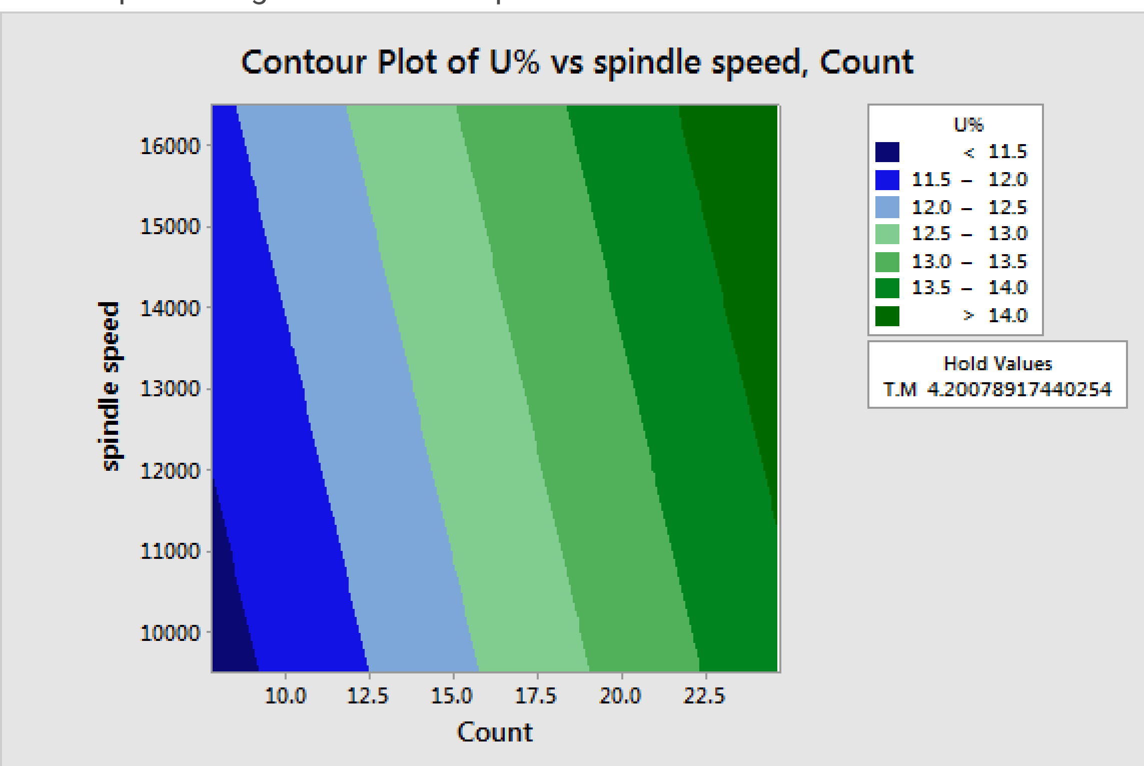

Figure 3

Counterplot U% against twist multiplier and count

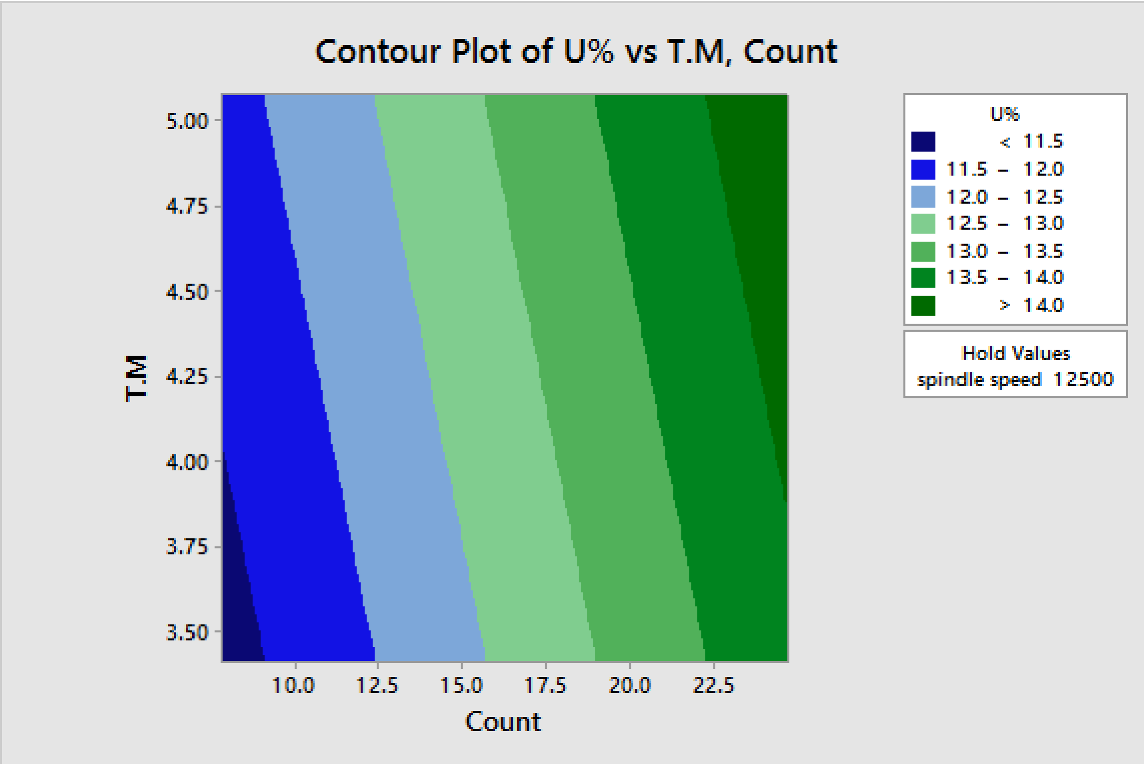

Figure 4

Counterplot U% against twist multiplier and count

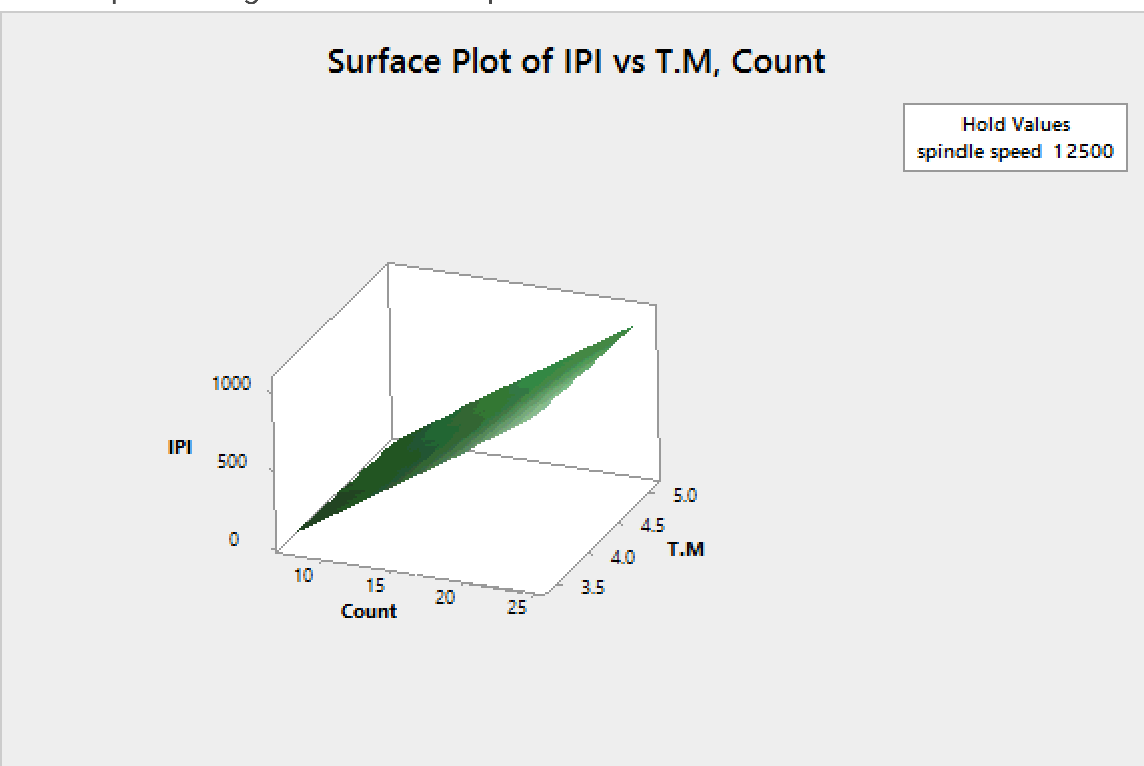

Figure 5

Surface plot IPI against Twist Multiplier and count

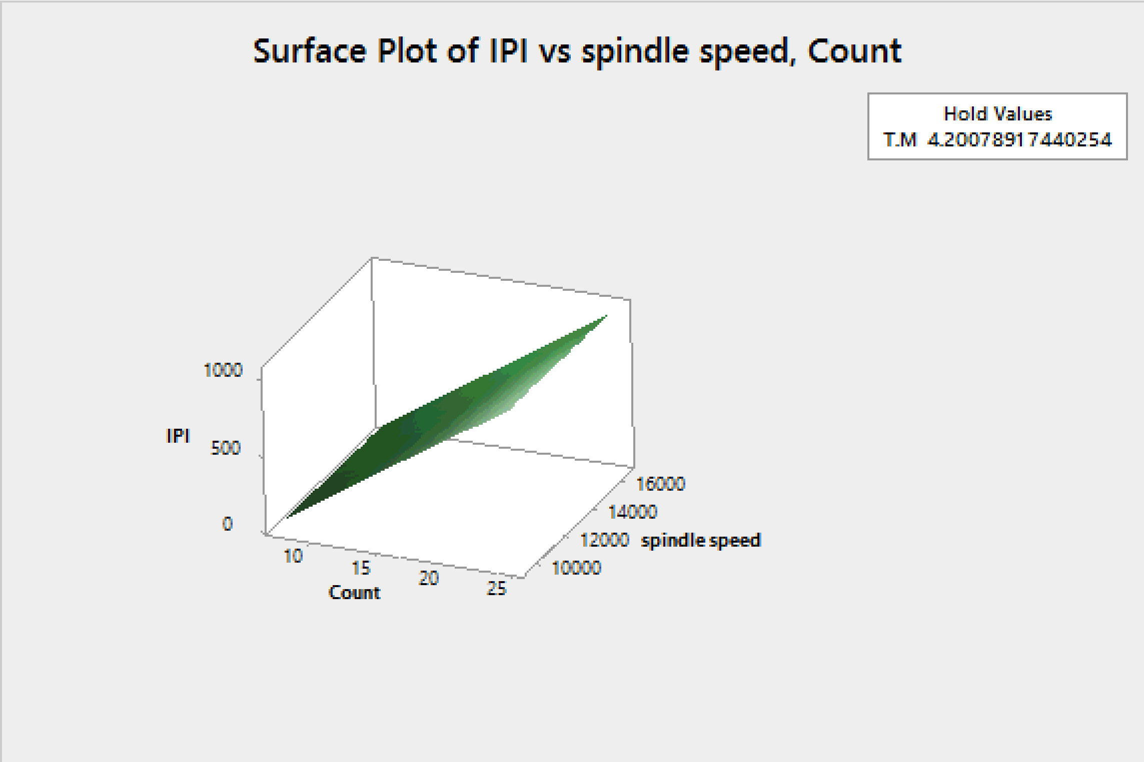

Figure 6

Surface plot IPI against. spindle speed and count

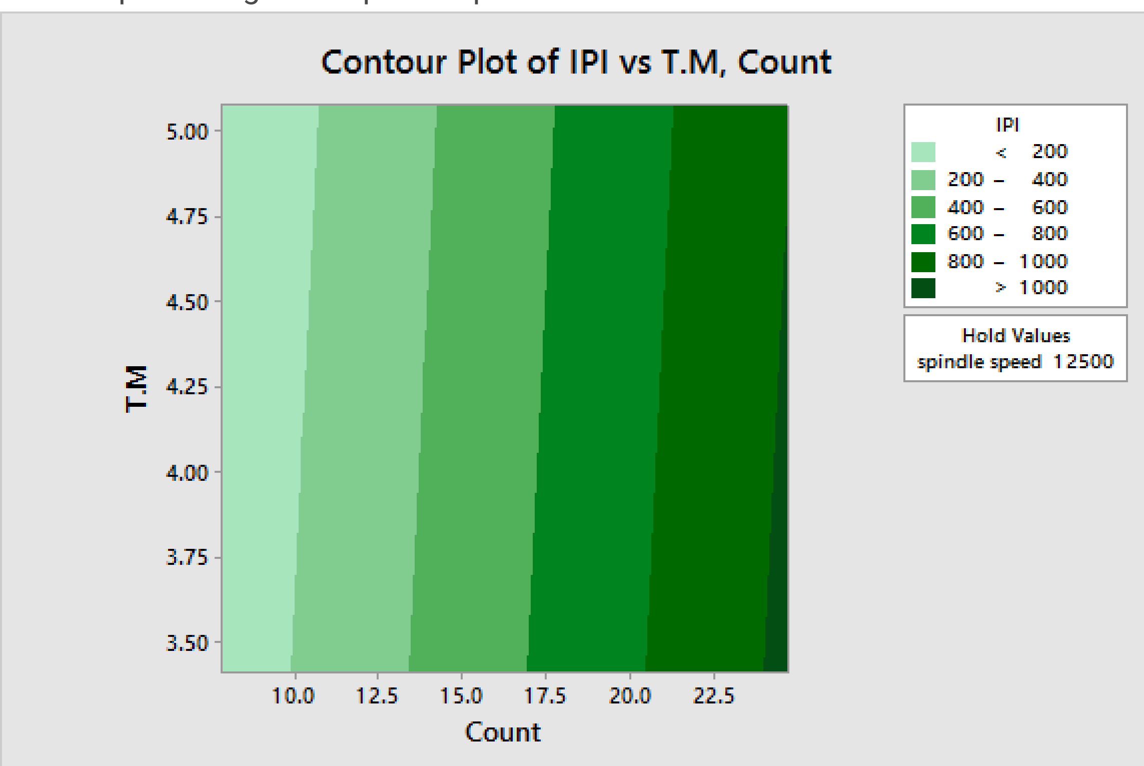

Figure 7

Counterplot IPI against spindle speed and count

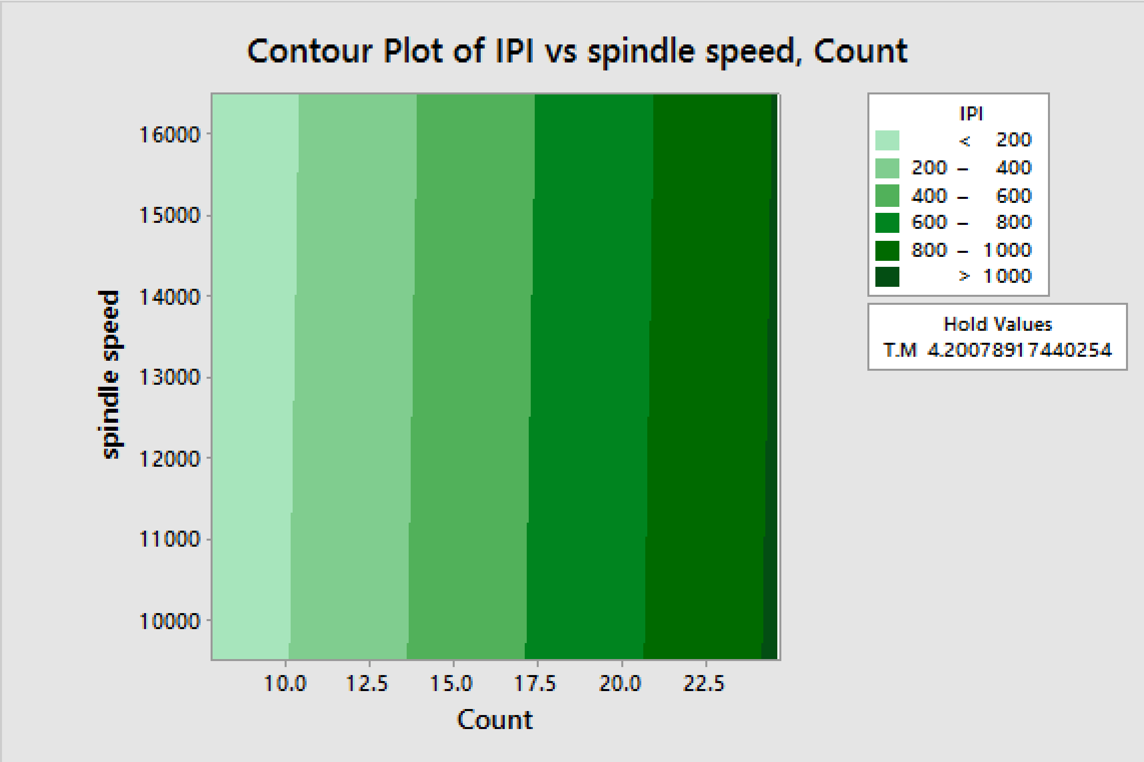

Figure 8

Counterplot IPI against spindle speed and count