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ARTIFICIAL NEURAL NETWORKS TO ENHANCE THE RING MACHINE EFFICIENCY AND YARN QUALITY BY DETERMINATION AND OPTIMIZATION OF DYNAMIC YARN TENSION

YAPAY SİNİR AĞLARI İLE DİNAMİK İPLİK GERİLİMİNİN BELİRLENMESİ VE OPTİMİZASYONU SAĞLANARAK RİNG MAKİNESİNİN ETKİNLİĞİ VE İPLİK KALİTESİNİN İYİLEŞTİRİLMESİ

Assad FAROOQ[1]
Nayab KHAN[1]
Khalil AHMAD[2]
Muhammad MOHSIN[2]
Usama AKHTAR[2]
Muhammad AWAIS[1*]
Fiaz HUSSAIN[1*]

[1]Department of Fiber and Textile Technology, University of Agriculture Faisalabad, Pakistan.
[2]Shahzad Textile Mills Ltd. Sheikhupura, Pakistan

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[1]Department of Fiber and Textile Technology, University of Agriculture Faisalabad, Pakistan.
[2]Shahzad Textile Mills Ltd. Sheikhupura, Pakistan

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ABSTRACT: The yarn spinning process involves the interaction of large varieties of variables. The relation between the dynamic yarn tension (DYT), yarn quality, and production efficiency of the spinning frame cannot be established conclusively. Artificial neural network (ANN) is a promising step in this filed. In this research work, ANNs simulation and modeling is applied for the optimization of the DYT n to improve the production efficiency and quality of yarn. The research to date in DYT is insufficient to meet the developmental requirement of the high-speed and efficient ring spinning frame. One of the major problems facing the effective use of the ANN is the correct selection of the input parameters to be fed for the training of ANNs. Data of various input variables such as count, traveler no., spindle speed and dynamic yarn tension etc., was used for ANN modeling and simulation. DYT plays a significant role in the determination of yarn quality and its productivity in terms of end breakage rate. However, it has never been explained in terms of displacement from the original yarn path. This work is aimed to the determination and optimization of DYT at ring spinning frame. The influence of different yarn geometry parameters on DYT, measured by the tensiometer was investigated. The optimized DYT values for the machines, running at different speed and different counts were determined using ANN modeling. It is found that the optimized values predicted from ANN resulted in better quality, high production, and decreased end-breakage at industrial ring spinning frames. By the implementation of ANNs the optimum speed and effective utilization of textile raw materials can be achieved.

Keywords: Artificial neural network, dynamic yarn tension, machine efficiency, yarn quality

YAPAY SİNİR AĞLARI İLE DİNAMİK İPLİK GERİLİMİNİN BELİRLENMESİ VE OPTİMİZASYONU SAĞLANARAK RİNG MAKİNESİNİN ETKİNLİĞİ VE İPLİK KALİTESİNİN İYİLEŞTİRİLMESİ

ÖZ: İplik eğirme işlemi, çok çeşitli değişkenlerin etkileşimini içerir. Dinamik iplik gerginliği (DİG), iplik kalitesi ve eğirme makinesinin üretim verimliliği arasındaki ilişki kesin olarak kurulamamaktadır. Yapay sinir ağları (YSA) bu alanda gelecek vadeden bir araçtır. Bu araştırma çalışmasında, ipliğin üretim verimliliğini ve kalitesini iyileştirmek için dinamik iplik gerginliğinin (DİG) optimizasyonunda YSA simülasyonu ve modellemesi kullanılmıştır. DİG'de bugüne kadar yapılan araştırmalar, yüksek hızlı ve verimli ring eğirme makinesinin gelişimsel gerekliliklerini karşılamak için yetersizdir. YSA'nın etkin kullanımında karşılaşılan en büyük sorunlardan biri, YSA'ların eğitimi için beslenecek girdi parametrelerinin doğru seçilememesidir. YSA modellemesi ve simülasyonu için iplik numarası, kopça numarası, iğ hızı ve dinamik iplik gerginliği gibi çeşitli girdi değişkenlerinin verileri kullanılmıştır. DİG, iplik kalitesinin belirlenmesinde ve iplik kopuş oranı açısından iplik üretim verimliliğinde önemli rol oynamaktadır. Bu duruma karşın orijinal iplik yolu ve yer değiştirmesi açısından hiçbir zaman açıklanmamıştır. Bu çalışma, ring iplik makinasında DİG'nin belirlenmesi ve optimizasyonunu amaçlamaktadır. Farklı iplik geometri parametrelerinin tansiyometre ile ölçülen DİG üzerindeki etkileri araştırılmıştır. YSA modellemesi kullanılarak farklı hız ve sayılarda çalışan makineler için optimize edilmiş DİG değerleri belirlenmiştir. YSA'dan tahmin edilen optimize edilmiş değerlerin, endüstriyel ring eğirme makinelerinde daha iyi kalite, yüksek üretim ve azalmış iplik kopması ile sonuçlandığı bulunmuştur. YSA'ların uygulanmasıyla, tekstil hammaddelerinin optimum hızı ve etkin kullanımı sağlanabilir.

Anahtar Kelimeler: Yapay sinir ağı, dinamik iplik gerginliği, makine verimliliği, iplik kalitesi,

****Sorumlu Yazarlar/Corresponding Authors:*** *fiaz.hussain@uaf.edu.pk, muh.awais@uaf.edu.pk,*
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1. INTRODUCTION

Although the advanced spinning technologies have solved the problem of production and automation to a great extent, the conventional ring spinning dominates the staple yarn spinning techniques due to its high quality, high strength, and flexibility compared to innovative spinning processes [1]–[3]. As ring frame cost comprises a major portion of total cost, the productivity at ring frame has assumed considerable importance and every effort to maximize production at this stage is worth exploring. Increasing spindle speed, production efficiency, and yarn quality of ring spinning has been the focus of many researchers for minimizing the cost of yarn [4]–[6]. Conventional ring spinning produces high-quality yarns, but the spinning efficiency is low and power consumption per unit of yarn production is high [1], [7], [8]. The low spinning efficiency is due to high tensions resulting from ring and traveler friction, which limits the production speeds.

Among various factors, dynamic yarn tension is the main influencing factor in the ring spinning machine which directly affects the quality and production of ring frame [6]. At the ring frame the yarn tension is divided into three tension zones namely spinning tension (from front roller nip to the snail wire), balloon tension (between snail wire and the ring), and winding tension (between the ring and the bobbin). The yarn breakage occurs mainly in the spinning zone; near the front roller nip, where the minimum twist is present. The tension in the winding tension is much higher than in the spinning tension [9]–[11]. However, the spinning yarn tension; between the front roller nip and the snail wire provides the true picture of the spinning geometry settings. The spinning tension and its fluctuations are directly associated with the ends down percentage at the ring spinning machine because mainly the yarn breakage occurs near the tip of the front roller; where the yarn has the least amount of twist inserted. When the yarn tension increases the strength of the weak place the yarn breakage occurs in the spinning tension zone. The dynamic yarn tension is the reflectance of spinning geometry parameters [12], [13]. The speed of the spindle, the frictional force of the traveler with the steel ring, traveler weight, diameter and surface of the ring, and the coefficient of friction between the ring and traveler are directly related to the spinning tension [13].

An artificial neural network (ANN) has the ability to model real-world scenarios even in the presence of noisy data. They can also model the processes with a large number of variables having non-linear relationships between them [14], [15]. In the textile industry, ANNs are being used for more than the last two decades and have proved efficient for modeling complex spinning problems [15]–[18]. However, the mathematical modelling, especially for the DYT is based on many assumptions/ideal values like traveler weight is constant, yarn density is constant throughout the length, and the ring friction is uniform throughout its diameter [19]–[23]. In the spinning industry, the DYT is measured manually at the ring frame with the hand or finger. The measurement of the yarn tension pertains to touching the yarn path in the spinning tension zone. However, as the yarn displaces from its original path an increased amount of tension is experienced that results in the breakage of the yarn and ultimately quality and production of the yarn is swearly affected [11], [24]. The solution for the best running conditions at the ring frame is to achieve an optimum yarn tension level that remains constant over a longer period. However, this optimized level is hard to achieve. The precise control of the yarn tension can help the ring spinning machines to run at higher speeds with fewer yarn breakages. It is believed that the quality and production of yarn at the ring spinning can be significantly enhanced by the determination and optimization of yarn tension using the ANNs. To the best of our knowledge ANNs are not applied for the determination and optimization of yarn tension at ring frame using the real time data to address the yarn breakage and quality issues of conventional ring frame.

In this backdrop, the proposed research work was carried out to measure the dynamic yarn tension in an efficient manner and to find out the optimum yarn tension in the relationship with the vital yarn spinning geometry variables. The results indicated that data of various factors such as yarn count, spindle speed, traveler no., ring life in months, displacement from the original position, and tension at different cop build up position can be used for the determination and optimization of the yarn tension using ANNs. It was found that at the optimized dynamic yarn tension, the speed of the ring frame can be increased. The increase in the spindle speeds resulted in the increased productivity. Moreover, it is also inferred that at the optimum tension the ends down rate is also significantly reduced. Our findings indicated that ANNs can be helpful to enhance the production and efficiency of ring-frame and this model can also help in the conservation of energy and textile raw materials. It is further believed that ANN has the potential along the entire textile process that should be further investigate and exploited.

2. MATERIALS AND METHODS

The polyester and cotton blended (PC: 52/48) yarns were prepared by the conventional ring spinning process. The key characteristics for cotton and polyester are summarized in Table 1. The simplex roving with 1.05 HR and 0.5 TM was used for the preparation of the yarns used in this study. For the determination of dynamic yarn tension, research is conducted on an industrial scale. DTM 500 tensiometer was used to measure the spinning tension *(Fig. 1)*. An attachment is devised to place the tensiometer between the front roller nip and snail wire. For the proper fixation of the device on the ring frame, the stand is equipped with a magnet that provides sufficient force to strongly attach to the ring frame to avoid vibrations. The two fixed pins of the probe were removed to avoid twist blockage to the spinning zone and consequently thread breaks. A Teflon rod was placed just above the topmost position of the lappet to avoid the swinging of the yarn in the spinning zone. This keeps a constant angle of wrap of the yarn over the movable pin at 150°. This instrument works on the principle of the differential capacitor. The tension probe was positioned in the spinning zone 8 cm below the front roller nip. When yarn passes over the movable pin of the probe, the pressure applied by the yarn causes a change in the voltage which is proportional to the yarn tension. Also, an electronic microscope is attached to measure the yarn displacement from the actual position in accordance with the change in tension (cN).

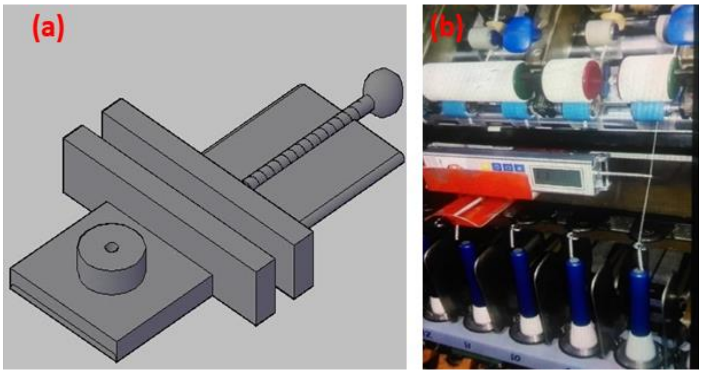

Figure 1. (a) DTM 500 Tensiometer, (b) Tension meter attachment at ring frame

The experiments of the yarn tension were performed with the polyester and cotton blended (PC) yarns. The experiments for the yarn tension measurement were conducted for three different yarn counts for PC blends (52:48) i.e., 20/1, 30/1, and 40/1. The optimum spindle speeds and traveler weights are different for every count. Therefore, the other influencing variables were varied from the optimum values. Moreover, the condition of the steel ring exerts a major influence on the yarn tension. Therefore, the working life of the steel ring was considered as a parameter. Along with the yarn tension, the displacement distance from the mean yarn passage was also considered as determining value. The displacement of the yarn from its original path increases the tension to an extent and then the yarn breaks after a certain displacement.

This mentioned arrangement is the conversion of the subjective evaluation of the yarn tension to an objective evaluation. The expert staff in the spinning industry use to check the tension by hand and try to feel the tension with a finger. Then they use the trial-and-error method to optimize the yarn tension and hence to control the end breakage and improve the quality and production efficiency at the ring frame. The dynamic yarn tension measurement arrangement that is used in this study is capable of determination of yarn tensions objectively.

RESULTS AND DISCUSSION

The present study was conducted to enhance the quality and productivity of the spinning process and to eliminate the trial and error at the ring-spinning frame. The subjective method of estimating the yarn tension was converted to the objective determination of the dynamic yarn tension as mentioned in the Section 2 (Materials and Methods). For this, the following parameters were considered in the determination of dynamic yarn tension at the ring-spinning frame and their corresponding yarn tensions were measured. The yarn tension determination using the following parameters helped to find the optimum yarn tension for a specific count,

- Yarn count
- Spindle speed
- Traveler no.
- Ring life in months
- Displacement from the original position
- Tension at different cop build up position.

In order to collect the reliable industrial data for this study, all the experiments were conducted in the Shahzad Textile Mills Sheikhupura, Pakistan on the ring spinning machines. The collected data was further used for the artificial neural network training for the determination of the optimum yarn tension. After the determination of the optimum yarn tension for different counts, the dynamic yarn tensions on all the ring spinning machines in the industry were determined. The difference between the optimum yarn tensions and determined yarn tensions were adjusted by changing the spindle speeds and adjusting the traveler nos. The increase in the spindle speeds has resulted in increased productivity. Moreover, it is also inferred that at the optimum tension, the ends down rate is also reduced which results in the conservation of energy and raw materials.

Table 1. Parameters of Cotton and Polyester fibers used in this study.

Cotton										
SCI	Moisture (%)	Mic	Mat	UHML (inch)	UI (%)	SF (%)	RD	+b	Strength (g/tex)	C. Grade
125	8	4.23	0.87	1.059	81.6	7	76.7	8.7	30.2	31-2
Polyesters										
Denier		Length (mm)								
1.2		38								

3.1 Influence of yarn count (ne)

The yarn tension with respect to counts were determined at the optimized spindle speeds of the ring-frame and the results are shown in *Fig. 2*. The tensiometer was used to measure the yarn tension. Different yarn counts have different spinning tension mainly due to differences in the number of fibers in the cross-section of yarn. This results in more cohesion between the fibers and hence more tensile strength. Therefore, courser counts can bear more tension than the finer counts. The same has been proved when the yarn tension was measured by displacing the yarn from its original path. The average spinning tension for 20/1, 30/1, and 40/1 is 11 cN, 9.4 cN, and 8.6 cN, respectively.

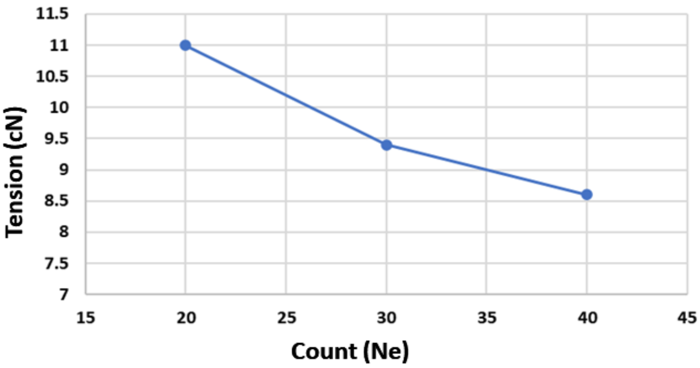

Figure 2. Measurement of spinning tension for different counts with a tensiometer

3.2 Influence of spindle speed:

The yarn tension of various counts (20/1, 30/1, and 40/1) at different the ring frame at different doffing positions; start, mid, and full of doff were determined and the results are shown in *Fig. 3*. It is obvious from the results that the yarn tension and ring frame speed increases with an increasing doff time. For 20/1 PC, at the start of doff at the spindle speed of 13000 rpm, the spinning tension is 11.8 cN, at the mid of doff, at the spindle speed of 15000 rpm the average spinning tension is 12.4 cN, and at the full of doff on the spindle speed of 16000 rpm, the average spinning tension is 12.8. So, the above graph presents that with the increase of spindle speed, the average spinning tension for 20/1 PC is increased. Similar findings were observed for PC 30/1 and PC 40/1. The yarn tension is increased with an increasing spindle speed. It can also be seen that the trend is quasi-linear. However, other factors like the condition of the steel ring and traveller also influence the yarn tension. However, the quasi-linear trend shows that other factors exert the same influence on all ring machines tested for the study.

The yarn tension is the result of many factors including spindle speed, condition of the steel ring, type and condition of the ring flange, weight condition of the ring traveler, friction of the spindle, centricity of the spindle, and yarn count etc. All these ring geometry paraments increase or decrease the yarn tension due to the friction between ring and traveler, and yarn and traveler, the smoothness of the spindle rotation and traveler rotation on its track on steel ring may decrease the friction and as a result yarn tension is reduced. This intern can reduce the yarn breakage and if the yarn tensions are optimized the spindle speeds can be increased which can increase the productivity of the spinning operation.

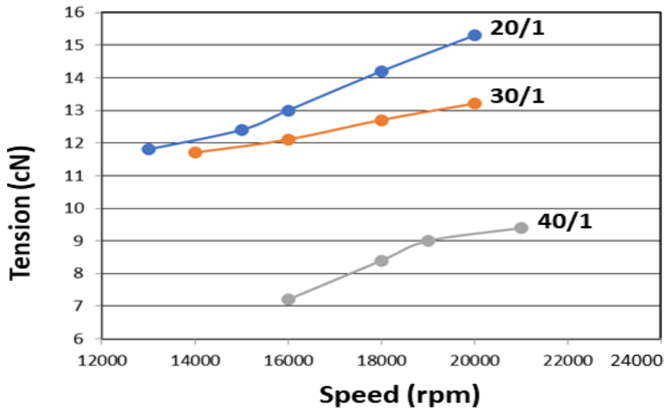

Figure 3. Dynamic yarn tension of different counts at different speeds

3.3 Influence of traveler and displacement distance

The core of the study depends on the measurement of the yarn tension at different displacement levels from the original yarn path. This method shows that how much spinning tension the yarn can bear before being broken. The displaced distance is directly proportional to the increase in the yarn tension. However, due to friction between the ring and traveler, there are tension peaks, especially in the winding tension and balloon tension which are then transported to spinning tension, i.e. between the snail wire and the nip of the front roller. If this tension increases than the strength of the weakest place in the yarn, the end down occurs. Therefore, yarn tension at a displacement is a vital measurement parameter to understand and predict the spinning geometry interactions and the optimum yarn tension. For this, the yarn tension at different displacement levels were determined and the results are shown in *Fig. 4*. The yarn tension was measured using different traveler numbers (no.3, no, 4, and no. 5) as shown in *Fig 5*.

The dynamic yarn tension of 20/1 was determined using traveler no. 3 at the spindle speed of 15800 rpm. It can be seen from *Fig. 4* that for 20/1 that an average tension at break was found to be 12.4 cN. At the displacement of 2.5 mm, 2.75 mm, 3.0 mm, and 3.75 mm, dynamic yarn tension of 7.0 cN, 8.0 cN, 10 cN, and 11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 12.4 cN. Similarly, an average tension at break was found to be 11.8 cN using the traveler no. 4 at the spindle speed of 15400 rpm. At the displacement of 1.75 mm, 2.5 mm, 3.0 mm, and 3.25, dynamic yarn tension of 5.0 cN, 7.0 cN, 10 cN, and11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 11.8 cN. The same is the case with traveler no. 5, an average tension at break was found to be 12.5 cN. At the displacement of 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm, dynamic yarn tension of 6.0 cN, 7.0 cN, 9 cN, and 11 cN was observed, respectively. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 12.5 cN.

The force generated by the motion of the traveller and the pulling of the yarn through the traveller around the spindle axis as well as the winding of the yarn onto the spinning cop causes yarn tensions, which define the actual shape of the spinning balloon [25]. There is a direct relationship between the number of travelers, which are metal rings guiding yarn during spinning, and the resulting tension in the spun yarn. The yarn experience increased tension with an increasing traveler number during spinning process. This inference has practical implications in the textile industry, where yarn quality and consistency are paramount. Choice of traveler no. can be strategic choice for manufacturers to control and optimize yarn tension, ultimately influencing the quality of the final product. Understanding this relationship is crucial for achieving desired yarn characteristics and production efficiency in the world of textile manufacturing. It can be inferred from the above discussion that an increase in the traveler no. tends to increase the spinning yarn tension. However, the ability to withstand the tension under the displacement from the original path decrease and so the ability to withstand the peaks in the tension originated from the ring traveler friction.

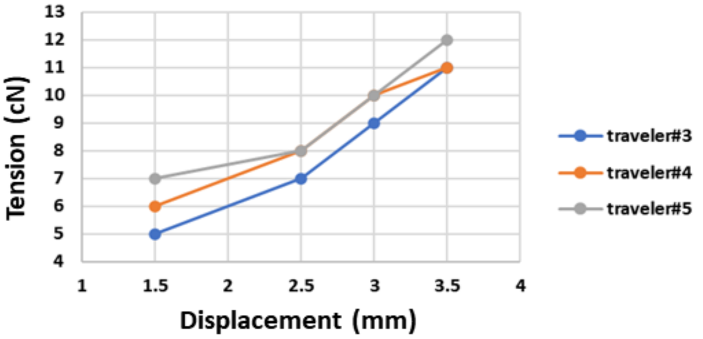

Figure 4. Dynamic yarn tension measurement of 20/1 using different travelers

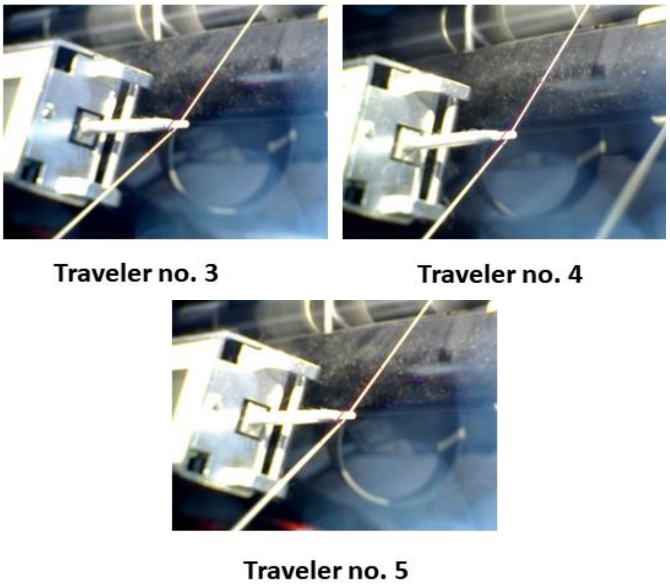

Figure 5. Yarn tension measurements at ring frame

Similarly, the relation between the dynamic yarn tension and different yarn displacements was determined for 40/1 and the results are shown in *Fig. 6*. For this experiment, the values for the dynamic yarn tensions were determined using traveler no. 1 at the spindle speed of 21000 rpm. The result reveals that an average tension at break was found to be 9.4 cN on this count. At the displacement of 1.0 mm, 1.5 mm, 2.0 mm, and 3.0 mm, tension of 4.0 cN, 6.0 cN, 7 cN, and 9 cN was observed, respectivley. It can be inferred that the yarn tension increases with the increase of displacement until it breaks after achieving a maximum average tension of 9.4 cN.

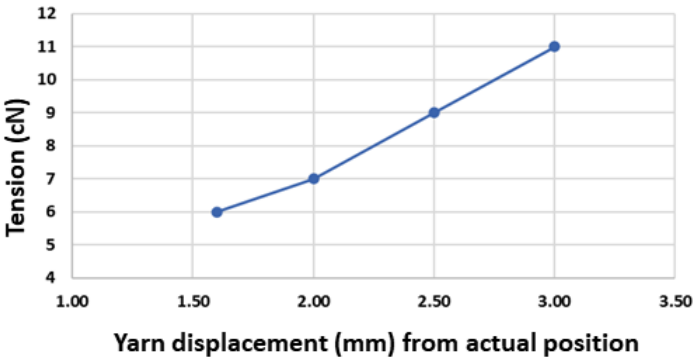

Figure 6. Dynamic yarn tension of 40/1 (Ne) at different yarn displacements

3.4 Influence of spindle speed and displacement distance

As the objective of the study is to enhance productivity and quality by reducing the end breakage and increasing the spindle speed. Therefore, this part of the study was designed to develop the relationship between the spinning yarn tension and the spindle speed at different displacement distances. As the spindle speed and traveler no. are the only two parameters in the spinning geometry that can be changed to increase or decrease the yarn tension.

The dynamic yarn tension of the 20/1 was determined at different speeds and different displacement distances and the results are shown in *Fig. 7*. It is evident from the results that the average tension increases with an increase in the spindle speed. However, as far as the displacement distance is considered it is shown that the trend is not quite linear. The increase in the displacement from 2.5 mm up to 3.5 mm, has a steeper slope in comparison with the yarn tension values at displacement distances below 2.5 mm.

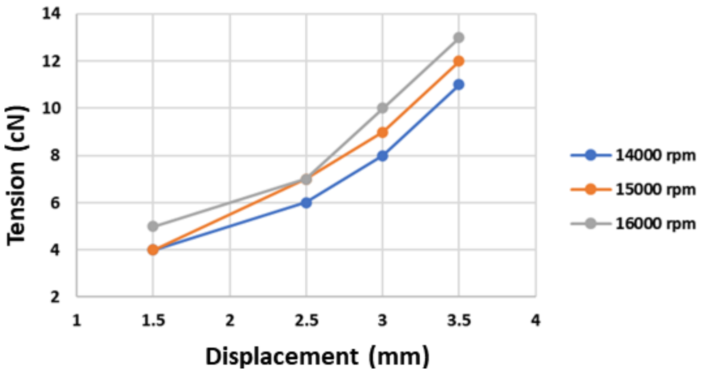

Figure 7. Measurement of dynamic yarn tension at different displacement and spindle speeds

Furthermore, the data reveals that at higher spindle speeds the yarns tend to break at lower displacement distances, which is attributed to the ability to bear less tension. The same case was observed when the heaver travelers were used. The same experiments were performed with the other yarn counts at higher spindle speeds and the data for artificial neural networks were collected.

For clarity and ease of understanding the results for the produced counts are summarized in Table *2*.

3.5 Artificial neural networks modeling and simulation

The data collected by changing different parameters at the ring spinning machine was subjected to artificial neural network training software Matlab Neural Networks Toolbox. The concept is to predict the optimum yarn tension at the given parameters. Different combinations of network structures, training parameters, and training algorithms were applied to achieve the best training of the neural network. Then the trained networks were tested against the unseen data both by the "hold-out" method and cross-validation technique. The training parameters are given in Table 3 while the performance of Artificial Neural Networks during training and testing is given in Table 4. The values measured were validated with values calculated from a model developed for the prediction of yarn tension at different zones and the results are shown in *Fig. 8*. The Fig shows the Artificial Neural Network on unseen data using the "hold-out" method. The mean absolute error expressed in terms of yarn tension is 0.6 cN. Cross-validation was also applied to the yarn tension data. The results show a mean absolute error of 0.45 cN for 10% Cross validation while an error of 0.74 cN is observed in the case of 20% Cross-validation.

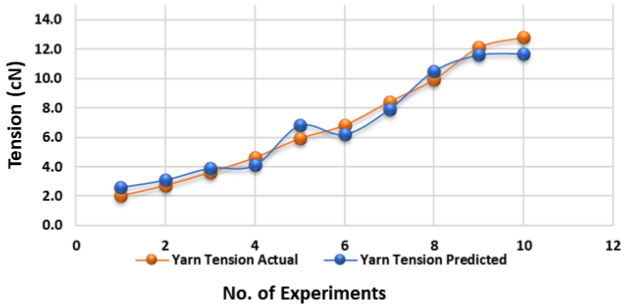

Figure 8. Test Performance for Yarn Tension.

Ring spinning geometry is of vital importance to control the end breakage rate in the spinning mill. The input parameters considered for the training of ANNs were the most influencing parameters. The parameters like steel ring condition cannot be considered in the other mathematical or statistical modelling. Whereas the steel ring condition generates uneven friction with the traveler and hence cause the yarn breakage. The above-mentioned ANN model was used to optimize the yarn tension on 25 spinning machines and the end breakage rate was calculated. It was found that the optimized DYN can results in low end breakage rate. Similarly, for the ring spinning machines having less dynamic yarn tension at different displacement points, the productivity of ring spinning machinery can be enhanced by increasing the spindle speeds.

Table 2. Summary for the 20/1, 30/1, and 40/1 yarn produced in this study.

Nec	U%	CV%	CV 1m	CV 10m	Thin -50	Thick +50	Neps +200	IPI	H	CLSP	TM	Speed (rpm) Thousand
40/1	12.0	15.01	4.34	2.69	9	300	491	800	4.00	2750	3.35	20800
30/1	11.23	14.35	4.84	2.63	4	179	290	473	5.49	3100	3.07	18000
20/1	9.41	11.95	4.07	2.01	0	36	83	119	6.6	3400	2.9	15000

Table 3. Neural network training parameters for yarn tension

Network Parameters	Values	Network Parameters	Values
No. of Input Neurons	6.0	Momentum	0.3
No. of neurons in the first hidden layer	6.0	Maximum Epochs	1000
No. of neurons in the second hidden layer	4.0	Stopping error	0.001
No. of neurons in the outer layer	1.0	Trained algorithms	Trainbr
Learning rate	0.1		

Table 4. Neural network training parameters for yarn tension

Network Performance	Mean absolute error (Expressed in terms of yarn tension)
Training Performance	0.4 cN
Testing Performance	0.6 cN
10 % Cross Validation	0.45 cN
20 % Cross Validation	0.74 cN

4 CONCLUSION

The optimization of the yarn tension at ring frame can reduce the yarn breakage and can improve the quality of the yarn produced. Artificial neural networks are one of the techniques by which the influence of complex relationship between the numerous variables on the predicted with accuracy. In this proposed project, the individual and combined influence of traveler weight, yarn count, spindle speed was studied on the dynamic yarn tension. Moreover, the method to determine the dynamic yarn tension on ring frame was also devised. Furthermore, industrial scale experiments were conducted, and their data was used as input for the neural network training and a model for the prediction of the dynamic yarn tension was developed. The results reveal that using optimized values predicted from artificial neural networks has decreased end-breakage at spinning frame, with improved yarn quality. The finding of this study can be used as a basis for the determination and optimization of yarn tension and reducing end breakage at ring spinning frame. Based on the findings, using artificial neural network can be a good step towards the automation of ring frame and it will result in the reduction of waste, conservation of energy. Factors like higher spindle speed and position of the ring rail also influence the yarn tension remarkably. These factors may be considered for future research work in this direction.

Limitations of the study

There are many parameters like elative humanity and raw materials that influence the quality and production. However, the proposed study pertains to the PC (52:48) blend of polyester and cotton.

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