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Assessing the Impact of Speed Change on Energy Consumption and Productivity: Investigating Ring Frame Process Parameters

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ABSTRACT
A concern in the contemporary period is to find balance in the world's ever-increasing demand and its severely constricted output given by the present energy crisis brought on by the post-pandemic and ongoing Russia-Ukraine war. One of the most fundamental human needs is met by the production of textiles. Spinning is the first step in the production of textiles, where the ring frame machine is essential for creating yarn. In this study, a few process parameters were altered in a ring frame machine to boost production while saving time and ensuring financial feasibility. Comparative analysis was performed based on financial aspects as well as quality concerns like yarn count variation, Count Strength Product (CSP), and end yarn breakage rate. The increased machine speed of the spinning ring frame consumes higher energy but yields higher productivity without compromising quality parameters. The findings enable the spinning industry's decision-makers to understand better how process parameters change when machine speed varies, as well as offer policymakers a clear picture of the correlation between energy consumption and profitability. The machine produces roughly 420 kg/day consuming 567 kWh of energy at 14000 rpm, with 2.57% breakages/100 spindles/hour of 18.48 tex count variation and CSP of 1320. However, the production and energy usage of a machine at 15000 rpm, is approximately 449 kg and 630.44 kWh/day. Respectively, with breakages 3.06%/100 spindles/hour of count variation 18.62 tex and CSP of 1325. A potential increase in profit of 112.58 USD/machine/day, or 9682 BDT resulted from the increase in machine speed.

KEYWORDS
energy consumption, ring frame machine, financial feasibility, productivity

INTRODUCTION

Textiles provide a significant contribution to the economic growth of countries that are heavily reliant on manufacturing-based industries [1]. To manufacture a textile good, raw materials must go through several processing stages. Spinning is the first and most important stage of producing yarn from fibres and filaments. People have been spinning fibres into yarn by hand for thousands of years. The current rotating frame is a mechanical marvel that operates in a flexible and trouble-free manner. Due to longer draft systems, bigger packages, faster speeds, as well as better materials and construction, spinning has improved substantially during the previous 25 years [2]. Recently, several techniques and diverse machinery have been invented for the spinning process, which has been utilized to make several types of yarn. The ring-spinning method is the most widely used in the spinning industry, incorporating several current processes to make yarn [3]. The ring spinning process start in the blow room through the winding stage, including the ring frame. The ring-spinning plant is divided into many components [4].

The ring frame machine is the last and most expensive as well as the most important spinning machine in the ring spinning process. On the ring-spinning machine, versatile ranges of yarn counts with the highest strength can be produced [5]. Due to rope-like fibre strands, producing a fine yarn through a large level of attenuation, the ring frame portion is considered to be a key component. For analysing the quality of the end product from the ring frame machine, different process parameters must be taken into consideration. One of them is cycle time, which is significant for evaluating the performance of ring frame machines. Cycle time is the sum of production run time and doffing time. The production run time is defined as the time from the start of the ring frame running when yarn begins to build up on the bobbin to the time when the ring frame automatically stops due to bobbins filling up with yarn. The doffing time is defined as the time required to replace full-ring cops with empty ones [6].

The quality of products and the efficiency of machines are the two most significant aspects to consider while evaluating a manufacturing facility. When producing high-quality yarn in a ring frame machine, things need to be taken into account: yarn breakage, count strength product (CSP), and count variation. Controlling the rate of yarn breakage at the ring frame is the first step toward enhancing ring frame productivity while maximizing yarn quality [7]. Strength, such as CSP, has also been considered one of the most essential qualities in textile engineering. Fabrics produced from high-strength yarns typically inherit higher strength [8].

When appraising the quality of the yarn, productivity should also be considered. Productivity is one of the most important variables in manufacturing industry, while the ultimate objective of any business is to make a profit [9]. In general, productivity refers to a machine's ability to turn raw materials into a usable product in the most efficient manner. Furthermore, the product is required to be manufactured in a better, cheaper, faster, simpler, and safer manner. Its goal is to make the most of available resources such as workers, machines, profit, power, land, capital, etc. In the manufacturing business, higher productivity is completing tasks in the quickest time feasible with the least number of inputs, without losing product quality [10].

Continuous investigation and moderation of process parameters are essential for increasing productivity with already available resources while improving yarn quality at the same time. Nowadays many manufacturers enhance productivity across the system to increase sales and give the business time to think about the future. Production investigation has several advantages, including increased equipment efficiency, reduced production delays, improved quality, and yield performance, and so on. By investigating the process parameters in the ring frame machine, it is possible to create high-quality yarn at a high production rate under adjustable processing conditions [11].

Most of the industry assumes that the higher the revolutions per minute (rpm), the higher the energy consumption is, and hence the higher the manufacturing cost [12,13]. As a result, the industry attempts to spend the least energy possible, i.e. to operate machines at maximum rpm to maintain optimum output costs [14]. Ring spinning process dominates the spinning business and is expected to remain the most extensively used type of spinning, since it offers substantial benefits in terms of yarn strength and flexibility over the new spinning technique [15]. Companies run ring frame machines at an optimal rpm because ring frame costs make up a significant amount of total costs. Manufacturers are reluctant to increase the ring frame machine's rpm above the appropriate level since it would raise production costs and decrease yarn quality.

Industrialists generally believe that greater machine speed implies higher energy consumption, significantly greater manufacturing costs, and a substantially lower profit margin. Numerous studies have been undertaken over the last few decades with a focus on the textile industry's energy usage. This entails determining the various areas where textile machinery uses energy as well as evaluating the inadequacies of energy conservation in textile mills, determining potential sources of electrical power losses in the textile industry, assessing various strategies for energy efficiency in textile machinery and so forth [16-18]. However, there are still no studies that compare the performance of various machine speeds across a ring frame by considering power and energy consumption, and the economic viability of increasing energy while keeping quality concerns in mind. For the mentioned research gaps, this study offers an investigative strategy for discovering various ring frame machine process parameters at different machine speeds. The research objectives of this study are:

- To determine how the increase in machine speed impacts power and energy consumption.
- To compare the increased energy costs by higher machine speed with the improved profit opportunities that would bring future yarn production growth.
- To evaluate whether the quality parameters are acceptable by evaluating them at a greater machine speed.

The investigation intends to illustrate a different outcome, where increased consumption maximizes spinning machine productivity while keeping optimum quality and profit levels.

In the study, a detailed breakdown of the ring frame machine's productivity is included, as well as machine rpm, energy consumption, doffing time, and so on. Respectively, we counted two distinct machine RPMs estimating the ring frame machine's production, energy consumption and yarn quality parameters. We also demonstrated a financial comparison between two different process operations.

MATERIALS AND METHODOLOGY

The research was conducted on a ring frame machine. The factory where the research was conducted primarily produces yarn in the range of 18 to 20 tex, which is the reason why the experiment was conducted with yarn of 18.5 tex. The detailed specifications of the machine are listed in Table 1.

Table 1. Machine specification

Machine	Ring frame
Brand	KTTM
Model	RXI240
Yarn count, tex	18.5
Twist per meter (TPM)	981.5
Doff length, m	1700
Total spindle number	1200
Maximum machine speed, rpm	17000

The three-phase current flow and voltage with the change in doff length and machine rpm were initially obtained to evaluate the change in energy consumption caused by an increase in machine speed. The interval between machine speed changes was measured. These data were used to compute power and energy consumption. Different yarn quality factors may be impacted by an increase in machine speed. Because of this, yarn quality parameters like breakage percentage, count variation and CSP was evaluated. Statistical regression analysis between machine speed and power consumption was used to determine the relationship between increased machine speed and power consumption. The economic viability of raising machine speed was then evaluated. The overall research methodology is illustrated in Figure 1.

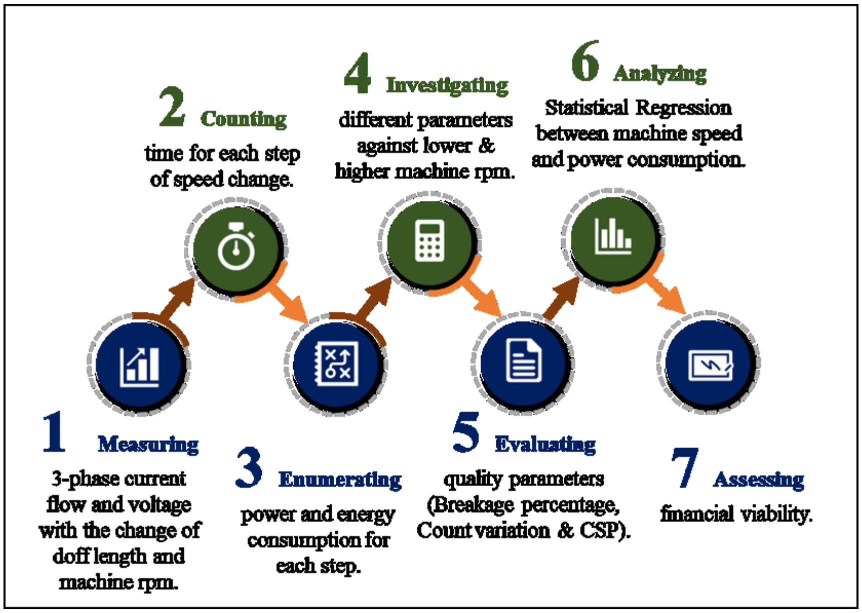

Figure 1. Research Methodology

Firstly the doff length at 1700 m was set and the machine was run at two different rpm, respectively at 14000 rpm and 15000 rpm. After completing each step of doff length, specified percentage, machine speed (rpm), values of three phases of current flow and three phases voltage have been evaluated. Based on obtained values, average current flow (I) and voltage (V) have been calculated. The time required to complete the production of the specified percentage of doff length has been counted. Afterwards, power consumption (P) have been calculated using the following equation [19]:

$$P = \sqrt{3}VI\mathrm{Cos}\theta \tag{1}$$

Where V is voltage (volt), I is average current flow (ampere), Cosθ is the power factor calculated as the ratio of working power (kW) and apparent power (kV A) (for spinning industry 0.9 is used as the power factor) [19].

After the calculation of the machine power consumption, the value of energy consumption for the specified percentage of doff length has been calculated using the following equation [20]:

$$Energy\ Consumption = Power\ Consumption \times time \tag{2}$$

Furthermore, the production value of the ring frame has been calculated by incorporating the following equation [4]:

$$Production = \frac{speed \times No.spindle \times efficiency \times yarn\ count \times doffing\ time}{TPI \times 39.37 \times 1000 \times 1000} \quad (3)$$

Where, production is expressed in kg/doff, speed is in rpm, efficiency is 96%, yarn coun in tex, doffing time in min, TPI is turns per inch

Consequently, the changes in doffs number, power and energy consumption, as well as daily production of the machine at two different machine rpm were investigated. The statistical regression analysis has been analysed between machine speeds and energy consumption to get a clear image of the interrelationship. Moreover, financial analysis has been evaluated between two rpm of the machine considering additional expense due to a rise in energy consumption and increased revenue with change in production. The mélange yarn fineness of 18.5 tex is taken into consideration in the calculation.

Lastly, to assure the quality aspect of the yarn, different quality parameters such as yarn breakage percentage, count variation and CSP for two different rpm of the machine have been evaluated.

For calculating the start-up breakage percentage, the change in end break after running the machine and end breaks from the previous doffing is counted. Start-up breakage percentages have been calculated using the mean number of breakages per spindle.

$$Start - up\ breakage = \frac{end\ breakage\ after\ running - end\ breakage\ after\ doffing}{number\ of\ spindle} \times 100 \quad (4)$$

The number of breakages/100 spindle/hour was calculated by considering the total number of breakages during the observed time using the following equation:

$$Breakages/100\ spindle/hour\ = \frac{total\ breakage \times 60 \times 100}{number\ of\ spindle \times observed\ time} \quad (5)$$

Where observed time is in min.

Additionally, the count variation of the produced yarn was measured. The English count of the yarn has been calculated by the following equation [21]:

$$Count = \frac{sample\ yarn\ weight\ x\ 1000\ m}{sample\ yarn\ length\ x\ 1} \quad (6)$$

Where count is in tex, sample yarn length in g m, sample yarn length in m.

After calculating the count, the CSP of the yarn has been measured using the following equation [22]:

$$CSP = strength\ of\ yarn\ \times count \tag{7}$$

Where the strength of the yarn is in the pound, the yarn count is in tex. As yarn count is expressed in tex, a higher CSP will replicate lesser strength.

RESULTS AND DISCUSSION

In Table 2, the change in machine speed (rpm), current flow, voltage, power and energy consumption concerning doff length change at 14000 rpm was presented. After completing 1% of the total doff length (17 m) within 1 minute and 31 seconds, the machine rpm was 11870, and the average current flow and voltage were 28.67 A and 386 V, respectively. Using obtained values as well as equations 1 and 2, the power consumption (17.23 kW) and energy consumption (0.43 kWh) were calculated. The machine runs for approximately 120 minutes to complete the target doff length of 1700 m. With each step of production, the targeted doff length with the change of time, machine rpm, current flow, voltage, power and energy consumption is increasing gradually.

Table 2. Change of different process parameters at 14000 rpm

Step	Completed production (%)	Completed production (m)	Speed (rpm)	Avg. current flow (Ampere)	Avg. voltage (Volt)	Power consumption, (kW)	Time (min)	Energy consumption (kWh)
1	1	17	11870	28.67	386.00	17.23	1.31	0.43
2	5	85	12035	28.87	385.00	17.33	5.19	1.54
3	10	170	13524	35.37	384.00	21.15	6,20	2.23
4	15	255	13922	37.70	386.00	22.66	6.01	2.27
5	20	340	14169	39.40	387.00	23.74	6.07	2.42
6	30	510	14417	42.10	386.33	25.32	11.48	4.98
7	40	680	14436	42.13	386.67	25.37	11.30	4.86
8	50	850	14402	41.90	384.67	25.09	11.39	4.87
9	60	1020	14428	43.93	386.33	26.43	11.41	5.14
10	70	1190	14418	43.97	384.00	26.29	11.26	5.01
11	80	1360	14446	43.47	383.67	25.97	12.05	5.23
12	85	1445	14466	44.80	385.00	26.86	5.40	2.54
			Average 14046	Average 39.67	Average 385.49	Total 356.99	Total 120.24	Total 49.36

Table 3. Change of different process parameters at 15000 rpm

Step	Completed production (%)	Completed production (m)	Speed (rpm)	Avg. current flow (Ampere)	Avg. voltage (Volt)	Power consumption, (kW)	Time (min)	Energy consumption (kWh)
1	1	17	12490	31.60	386.33	19.01	1.21	0.43
2	5	85	12729	31.80	386.67	19.14	5.10	1.65
3	10	170	13939	37.30	386.33	22.44	6.18	2.36
4	15	255	14363	41.43	385.00	24.84	5.52	2.43
5	20	340	14885	43.00	385.00	25.78	5.38	2.42
6	30	510	15558	46.50	382.67	27.71	10.52	5.02
7	40	680	15540	48.30	384.33	28.90	11.14	5.41
8	50	850	15529	48.83	384.33	29.22	10.25	5.07
9	60	1020	15514	48.57	385.67	29.16	10.42	5.20
10	70	1190	15516	49.77	386.33	29.94	11.33	5.76
11	80	1360	15537	50.50	388.00	30.51	10.37	5.39
12	85	1445	15508	50.27	388.33	30.39	5.10	2.62
			Average	Average	Average	Total	Total	Total
			14904	43.97	385.84	396.28	112.42	51.53

Table 3 shows the machine speed (rpm), current flow, voltage, power, and energy consumption vary when the doff length changes at 15000 rpm. The machine speed is observed to be 12490 after completing 1 per cent of the complete doff length (17 m) in 1 minute and 21 s. The average current flow and voltage are 31.60 A and 386.33 V, respectively. The power and energy consumption (19.01 kW and 0.43 kWh) are computed using equations 1 and 2. The machine was run for almost 112 minutes to complete the 1700 m of targeted doff length. The machine rpm, current flow, voltage, power, and energy consumption increased with each step of the manufacturing process up to the desired doff length as time passed.

From Tables 2 and 3 is obvious that the production is almost the same (approximately 36 kg) on two different machine speeds (14000 and 15000 rpm) as doff length has been fixed for rpm at 1700 meters. It can be seen that the energy consumption increases from 49.36 kWh to 51.53 kWh after producing the specified doff length (1700 m) with the increase in machine speed. At the higher machine speed value energy consumption increases, but less time in needed to complete the targeted production. Running the machine at 15000 rpm, the process takes 7.82 minutes less to complete the doff length, i.e. targeted production. The cycle time is estimated by adding the production time and the average doffing time (Table 4).

Table 4. Comparison of different parameters between 14000 and 15000 rpm

Sl.	Parameters	At 14000 rpm	At 15000 rpm
A	Production (Kg) per doff	36.6	36.7
B	Energy consumption (kWh) per doff	49.36	51.53
C	Production run time (minutes:seconds) per doff	120:24	112:42
D	Average doffing time (minutes) per doff	5	5
E	Cycle time (C+D) per doff	2.09 Hours	1.96 Hours
F	No. of doff per day (24÷E)	11.48	12.23
G	Production per day (Kg/Day) (A×F)	420.17	448.84
H	Unit energy consumption per day (kWh/Day) (B×F)	566.65	630.44

With the change in machine speed, obtained cycle time is 2.09 and 1.96 hours respectively, at lower and higher machine speeds. Table 4. shows that at higher rpm number of doffs per day increases with comparatively lower cycle time.

Table 1. Breakage comparison at 14000 rpm and 15000 rpm

Parameters	14000 rpm	15000 rpm
End break after doffing	13	24
End break after running	46	61
Start-up breakage, %	2.75	3.08
Total breakage	62	69
Breakages/100 spindle/h, %	2.57	3.06

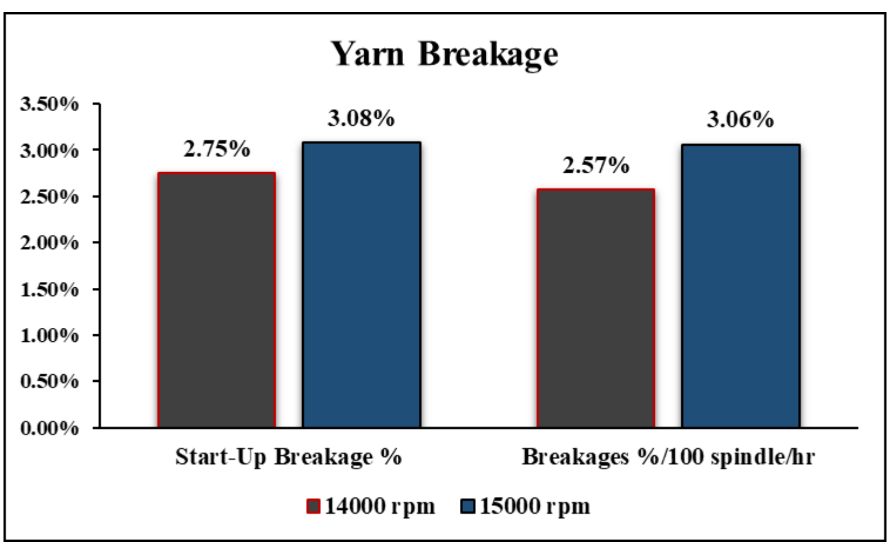

Figure 2. Breakage comparison at 14000 and 15000 rpm

With the increase in machine speed, there is a concern about the yarn quality. As a result, certain critical yarn quality parameters are assessed as machine speed changes. For the yarn breakage (Table 5, Figure 2) it has been determined that the start-up breakage percentage is 2.75% at 14000 rpm and 3.08% at 15000 rpm. Breakages per 100 spindles per hour were 2.57% at 14000 rpm and 3.06% at 15000 rpm.

When evaluating yarn quality, count variation is another crucial factor to consider. For testing the yarn count, a wrap reel and electrical balance have been used. The yarn length was 109.7 m. Following equation 6 count of multiple samples have been computed and the average value has been considered for comparative analysis. The average count of the 18.5 tex yarn was 18.48 tex at 14000 rpm and 18.62 tex at 15000 rpm (Figure 3).

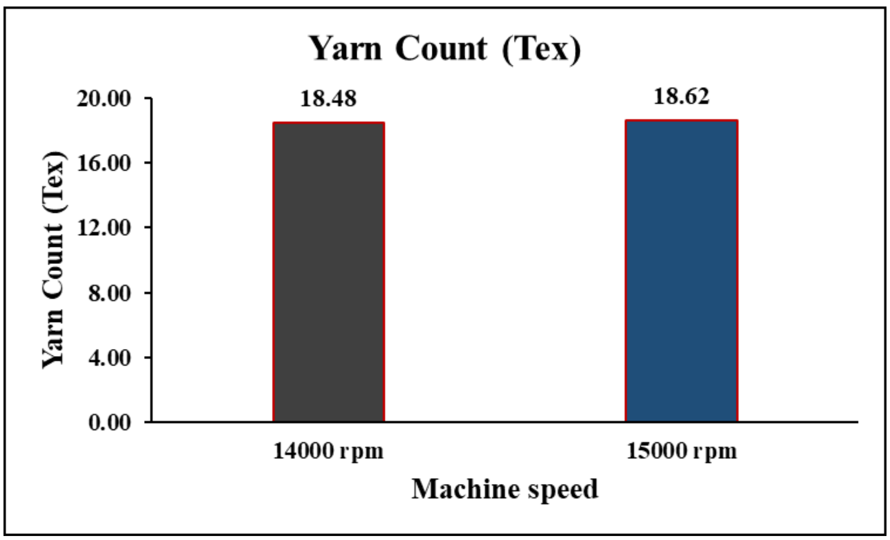

Figure 3. Count variation comparison at 14000 and 15000 rpm

Finally, another major concern with operating machines at greater speed is the end product's strength. A Lea strength tester has been used to identify the strength of the yarn. Using equation 7, CSP has been calculated. At lower rpm the CSP is 1319.57 and at higher rpm the CSP is 1324.62 (Figure 4).

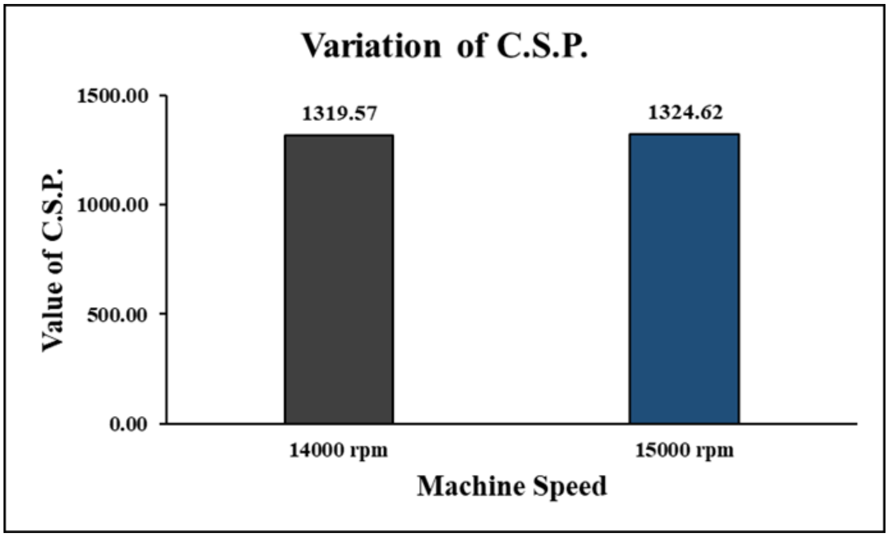

Figure 4. Comparison of CSP variation at 14000 and 15000 rpm

DISCUSSION

In this study, power consumption using a stepwise variation in machine speed has been measured. A statistical regression analysis has been carried out to determine the correlation between these two parameters.

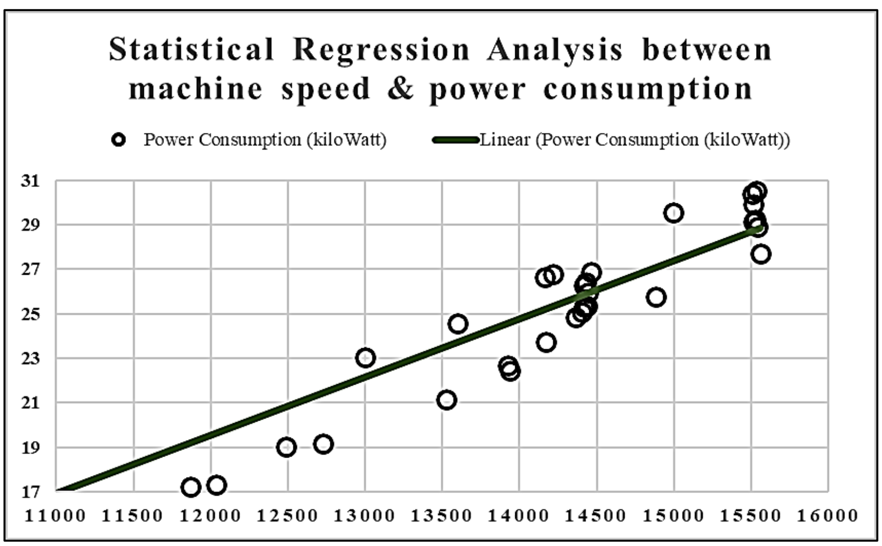

Figure 6. Statistical regression analysis between machine speed and power consumption

Figure 5 depicts the data clustering around the line indicating a linear relationship between machine speed and power consumption. Therefore, increasing machine speed will result in increased power consumption, which over time will lead to a rise in energy consumption.

The main two key points are the changes in production with the changes in energy consumption. There is a graphical representation of these juxtapositions. Figure 6 shows with increasing machine speed production and energy consumption per day increase too. It can be stated that with an increase in machine rpm, an increase in production and energy consumption occurs, respectively 6.82% and 11.26%.

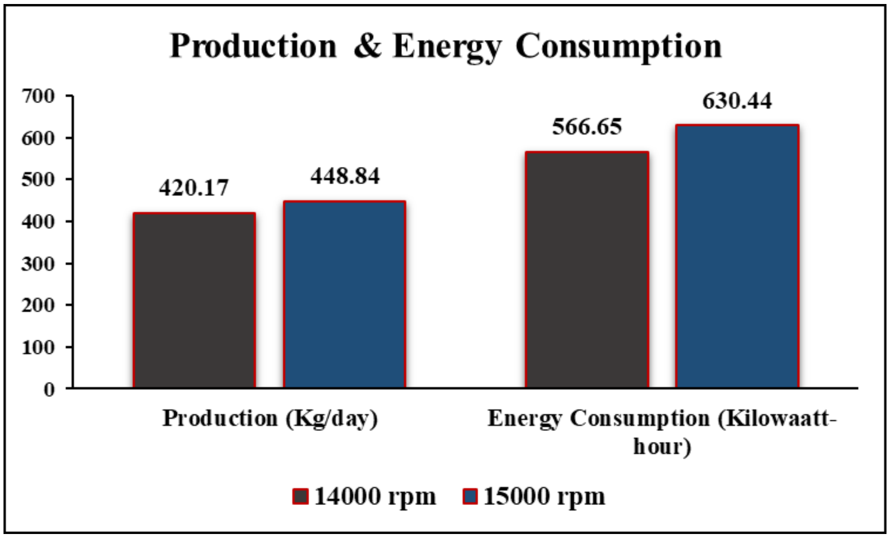

Figure 6. Change of production and energy consumption at variable machine speed

The increase can be justified with a financial comparison. When machine speeds are increased, energy consumption rises as well, adding to the operational costs. Table 6 shows that raising the machine speed results in an increase of 63.79 kWh of energy, which adds to the production cost of 673.63 BDT or 7.83 USD/machine/ day.

Table 6. Financial comparison per machine per day

Increase in energy consumption, kWh	63.79
Unit price of energy	10.56 BDT/kWh [23]
Additional expense	673.63 BDT or 7.83 USD [24]
Increase in production	28.67 kg
Unit price of yarn (18.5 tex)	$4.20/kg or 361.2 BDT/kg [25]
Additional revenue	10355 BDT or 120.41 USD
Increase in potential profit	9682 BDT or 112.58 USD
(Considering all the other associated costs same for both machine speeds)	

* Taking 1USD=86 BDT during the investigation

However, increasing machine speed not only raises energy consumption but also saves time which aids in additional production. Increasing the machine speed enhances yarn production by approximately 29 kg, adding revenue of 10355 BDT or 120.41 USD per machine each day (Table 6). Finally, from the analysis, an increase in potential profit of almost 9682 BDT or 112.58 USD from each machine per day arise, assuming all the other related cost are constant. If a manufacturing plant has 50 ring frame machines, the company will have a huge profit margin after a month without comprising the prime concern of yarn quality or putting machines at any risk.

The yarn quality is another issue to consider when increasing machine speed, because it is generally believed that greater speeds may cause more yarn breakage, thus lowering yarn quality.

However, the research reveals that the difference between the start-up yarn breakage percentage at lower and higher machine speeds (14000 rpm and 15000 rpm) is incredibly small (0.33%). Additionally, there is a 0.49% increase in breakages per 100 spindles per hour. After evaluating these data, the alterations acquired at lower and higher machine speeds are acceptable when compared to typical industrial practices. This analysis shows that the difference in average yarn count and CSP considering lower and higher rpm is insignificant, which strengthens the study.

CONCLUSION

Investigating the process parameters for a machine will give a clear understanding of its current state and open the door to potential future improvements to boost productivity. In this study, 18.5 tex yarn has been produced by varying machine speeds of the ring frame machine. The ring frame process parameters such as machine speed (rpm), current flow, voltage, power, and energy consumption with the change of doff length have been analysed. The product's quality such as end breakage rate, CSP and count variation at 14000 rpm and 15000 rpm were investigated. The investigation highlights that after increasing machine speed, energy consumption as well as production increases without compromising yarn quality or machine health. Moreover, financial analysis implies that additional revenue exceeds the additional expense incurred due to raising machine speed. This research may aid policymakers in spinning industries while making decisions regarding the implementation of proposed operational parameters while keeping financial viability in mind. This study will open new possibilities for process optimization in the spinning industry. Future studies will benefit from the obtained information as it relates to understanding various spinning process characteristics, including calculating production, breakage percentage, CSP, and other related concepts. This research can further be extended to study different machine brand of ring frame and by varying different yarn count to settle down a fixed operation parameter.

Author Contributions

Conceptualization – Alam MFB, Rahman MM; methodology – Alam MFB, Rahman MM; formal analysis – Alam MFB, Islam MT; investigation – Alam MFB, Islam MT; resources – Alam MFB, Rahman MM; writing-original draft preparation – Alam MFB, Islam MT, Hossan MM; writing-review and editing – Alam MFB, Islam MT; visualization – Alam MFB, Islam MT; supervision – Alam MFB, Islam MT. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest

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REFERENCES

[1] Kazancoglu I, Kazancoglu Y, Yarimoglu E, Kahraman A. A conceptual framework for barriers of circular supply chains for sustainability in the textile industry. Sustainable development. 2020; 28(5):1477-1492. https://doi.org/10.1002/sd.2100

[2] Rusca RA, Brown RS. Some Historical and Technical Aspects of Spinning. Textile Research Journal. 1956; 26(6):460-469. https://doi.org/10.1177/004051755602600611

[3] Kumar A, Ishtiaque SM, Salhotra KR, Senthil Kannan MS. Impact of different stages of spinning process on fibre orientation and properties of ring, rotor and air-jet yarns: Part 1- Measurements of fibre orientation parameters and effect of preparatory processes on fibre orientation and properties. Indian Journal of Fibre and Textile Research. 2008; 33(4):451-467.

[4] Ahmad N, Hossen J, Ali SM. Improvement of overall equipment efficiency of ring frame through total productive maintenance: a textile case. The international journal of Advanced Manufacturing Technology. 2018; 94:239-256. https://doi.org/10.1007/s00170-017-0783-2

[5] Khurshid MF, Nadeem K, Asad M, Chaudhry MA, Amanullah M. Comparative analysis of cotton yarn properties spun on pneumatic compact spinning systems. Fibres & Textiles in Eastern Europe. 2013; 101(5):30-34.

[6] Yin R, Ling YL, Fisher R, Chen Y, Li MJ, Mu WL, Huang XX. Viable approaches to increase the throughput of ring spinning: A critical review. Journal of Cleaner Production. 2021; 323:129116. https://doi.org/10.1016/j.jclepro.2021.129116

[7] Kumar RS. Process management in spinning. CRC Press; 2014. 416 p.

[8] Nurwaha D, Wang XH. Comparison of the new methodologies for predicting the CSP strength of rotor yarn. Fibers and Polymers. 2008; 9:782-784. https://doi.org/10.1007/s12221-008-0122-1

[9] Gopalakrishnan M, Skoogh A, Salonen A, Asp M. Machine criticality assessment for productivity improvement: Smart maintenance decision support. International Journal of Productivity and Performance Management. 2019; 68(5):858-878. https://doi.org/10.1108/IJPPM-03-2018-0091

[10] Stainer A. Capital input and total productivity management. Management Decision. 1997; 35(3):224-232.

[11] Iqbal S, Pramanik P, Haragopal VV. Optimization of Ring Frame Process Parameters for Fancy Multicount Yarn Part I: Ne 9.5 s Multicount Yarn. Research Journal of Textile and Apparel. 2012; 16(1):97-102.

[12] Mouzon G, Yildirim MB, Twomey J. Operational methods for minimization of energy consumption of manufacturing equipment. International Journal of Production Research. 2007; 45(18-19):4247-4271. https://doi.org/10.1080/00207540701450013

[13] Kulkarni KM, Sahu AR. Brief Overview on Study of Various Parameters Affecting the Productivity of Cotton Yarn. In: Kolhe ML, Jaju SB, Diagavane PM, editors. Smart Technologies for Energy, Environment and Sustainable Development, Vol 1. Singapore: Springer; 2022. https://doi.org/10.1007/978-981-16-6875-3_77

[14] Hasanbeigi A, Price L. A review of energy use and energy efficiency technologies for the textile industry. Renewable and Sustainable Energy Reviews. 2012; 16(6):3648-3665. https://doi.org/10.1016/j.rser.2012.03.029

[15] Hasanuzzaman, Dan PK, Basu S. Optimization of ring-spinning process parameters using response surface methodology. The Journal of The Textile Institute. 2015; 106(5):510-522. https://doi.org/10.1080/00405000.2014.929250

[16] Dhayaneswaran Y, Ashokkumar L. A study on energy conservation in textile industry. Journal of The Institution of Engineers (India): Series B. 2013; 94(1):53-60. https://doi.org/10.1007/s40031-013-0040-5

[17] Qaisar MH, Khattak A, Bilal M, Imran K, Ulasyar A. Electrical Energy Management in Spinning Area of Textile Industry. In: 2021 4th International Conference on Energy Conservation and Efficiency (ICECE); 2021 Mar 16-17; Lahore, Pakistan. IEEE; 2021. p. 1-6. https://doi.org/10.1109/ICECE51984.2021.9406279

[18] Rajput SK, Dheer DK, Wadhwani S. Improving Energy Efficiency of Ring Frame Motor of Textile Industry. In: Dubey HM, Pandit M, Srivastava L, Panigrahi BK, editors. Artificial Intelligence and

Sustainable Computing. ICSISCET 2020; Gwailor, India. Springer; 2022. p. 377-386. https://doi.org/10.1007/978-981-16-1220-6_32

[19] Ooi BT, Salmon JC, Dixon JW, Kulkarni AB. A three-phase controlled-current PWM converter with leading power factor. IEEE Transactions on Industry Applications. 1987; IA-23(1):78-84. https://doi.org/10.1109/TIA.1987.4504869

[20] Lewis AW, Ghosh S, Tzeng NF. Run-time Energy Consumption Estimation Based on Workload in Server Systems. In: HotPower'08: Proceedings of the 2008 conference on Power aware computing and systems; 7 Dec 2008; San Diego, CA. San Diego, CA; Usenix Association; 2008. p. 17-21.

[21] Zuo Q, Salleh KM, Wang C, Liu S, Lu C, Wang L, Li Y, Yi X, Zakaria S. Prediction and analysis of properties of ramie fiber staple yarn reinforced unsaturated polyester composite based on fiber packing density. Composites Part B: Engineering. 2022; 237:109869. https://doi.org/10.1016/j.compositesb.2022.109869

[22] Iftikhar F, Ali Z, Hussain T, Nazir A, Adolphe DC. Influence of yarn count and cover factor on mechanical, comfort, aesthetic and hand properties of ladies' summer apparel fabrics. Journal of Natural Fibers. 2021; 18(11):1592-1603. https://doi.org/10.1080/15440478.2019.1692322

[23] Bangladesh Energy Regulatory Commission. Retail Electricity Tariff Rate 2020. Dhaka, Bangladesh: Bangladesh Energy regulatory Commission; 2020. 5 p. Available from: http://berc.org.bd/sites/default/files/files/berc.portal.gov.bd/notices/86133373_6e68_4c88_aa49_237ba16263b4/2020-06-10-17-55-362cec32305a6e4f0bc17975a92e05e0.pdf

[24] Bangladesh Bank. Exchange rate of Taka. 25 Aug 2022. Available from: https://www.bb.org.bd/en/index.php/econdata/exchangerate

[25] The Daily Star. Yarn price fixed at $4.20 per kg. 2022. Available from: https://www.thedailystar.net/business/economy/industries/news/yarn-price-fixed-420-kg-2157971