Statistical Model for Predicting Compressed Air Consumption on Air-Jet Looms

Abdul Jabbar, Shakeel Ahmed, Tanveer Hussain, PhD, Noman Haleem, Faheem Ahmed

National Textile University, Faisalabad, Punjab PAKISTAN

Correspondence to:
Tanveer Hussain email: hussain.tanveer@gmail.com

ABSTRACT

Compressed air is a major component of energy costs incurred in the weaving of textile fabrics on air-jet looms. The consumption of compressed air in air-jet weaving depends on different process variables. In this study, the effect of weft yarn count, reed count, fabric width and loom speed on the compressed air consumption of air-jet loom was determined using response surface methodology. Fabric width was found to be the most dominant factor affecting the air consumption followed by loom speed, reed count, and weft yarn count respectively. A statistical model for predicting the compressed air consumption on air-jet loom was developed. The prediction ability and accuracy of the developed model was assessed by the fitted line plot between the predicted and actual air consumption values. The prediction model may be used for optimizing the production planning, estimating the share of compressed air cost in weaving a particular fabric style, and in identifying any air wastages in the weaving shed by comparing the actual compressed air consumption with that predicted by the model which was developed under controlled conditions without any air leakages.

Keywords: Compresses air consumption, Air-jet loom, Prediction, Statistical model, Correlation analysis

INTRODUCTION

Weaving is a well-known fabric production process comprising interlacement of warp and weft yarns on a weaving machine commonly known as “loom”. Looms are broadly classified into shuttle looms and shuttle-less looms. On the basis of weft insertion mechanism, shuttle-less looms are further classified into projectile, rapier, water-jet, and air-jet looms. Air-jet looms have become quite popular in the textile industry due to their high productivity and better controllability[1]. Air-jet looms utilize compressed air for weft insertion and can weave almost all types of yarns into fabric at a very high speed compared to other types of looms. The air guiding system used in air-jet looms consists of multiple nozzles and a profiled reed. The weft is inserted due to the frictional drag of compressed air jet coming from a main nozzle. Sub-nozzles are provided along the profiled reed to support the weft yarn during its insertion.

Despite several advantages of air-jet looms, their one major limitation is high energy cost for generating the required compressed air. Air compressors are considered the major consumers of electrical energy in a weaving mill, often comprising hundreds of looms running at a time [2]. Several attempts have been made by machine manufacturers and researchers to reduce compressed air consumption to some extent without compromising the loom performance and fabric quality. Masuda et al. [3] developed a new supplementary apparatus, which mechanically assists the weft insertion, for the reduction of compressed air and ultimately the electrical energy. The energy consumption of the compressed air was found to be reduced from 10 to 30 % with the new apparatus. Ishida and Okajima [4, 5] and Jeong et al. [6] developed a better nozzle design to improve the efficiency of the air-jet during weft insertion and to reduce air consumption. A decrease of the air consumption by 21% was achieved by decreasing the hole diameter of single-holed relay nozzle and by optimizing the blowing time of multi-holed relay nozzles [7]. Belforte et al. [8] analyzed the effect of different sub-nozzle geometries on pneumatic weft insertion and compressed air consumption. It was pointed out that single-hole nozzles give best performance instead of porous nozzles.

The effect of different yarn parameters on the behavior of pneumatic weft insertion has also been studied. The yarn linear density, structure, and twist are considered the main factors affecting the suitability of pneumatic weft insertion [9]. The effect of yarn twist direction was found not to be significant on air-jet weft insertion [10]. The yarn velocity in the weft insertion channel increases with the increase in number of filaments due to the larger yarn surface in contact with the air [11]. The influence of fiber properties, rotor yarn production parameters and yarn properties on the weft yarn insertion speed, were investigated by Githaiga et al. [12]. The fiber quality and yarn production parameters were found to have significant influence on the weft yarn insertion speed and with respect to the yarn properties, high correlation coefficients were obtained between the experimental and the predicted values of the yarn speed. Kayacan et al. [13] investigated the effect of yarn parameters on the weft yarn velocity. The effect of the yarn twist coefficient on weft yarn speed at different yarn linear densities was determined by using fuzzy logic. It was concluded that high yarn twist coefficient reduces the yarn speed and increases the insertion time and increase in yarn count increases the speed of weft yarn.

Although quite a few works have been reported so far on the reduction of air consumption on air-jet loom by optimizing the main nozzle, sub-nozzles designs and geometries, and reed profile, the prediction of air consumption on an air-jet loom has not so far been reported. The main objective of this work was to determine the relative importance of various process parameters on the compressed air consumption and to develop a statistical model in order to predict the compressed air consumption on air jet looms. Such a model may be helpful for weaving plant managers to optimize the production planning of their weaving shed, taking into account the compressed air generation capacity of the plant and the styles of fabrics to be woven at a time. The model may also be helpful in identifying compressed air wastages in a weaving shed by comparing the actual air consumption to that predicted by the model which was developed under controlled production conditions with no air leakages. Furthermore, the model may also be used for estimating the share of air consumption cost for a particular style of fabric.

MATERIALS AND METHODS

Four factors: weft yarn count (Ne), reed count (dents/inch), fabric width on loom (inches), and loom speed (rpm) were selected as input variables. The levels of the selected factors are given in *Table I*. The air consumption on the air jet loom was measured, according to combinations of different factor levels as given in *Table II*, using theTR-7900 air flow meter by Takayama Reed Company Limited, Japan. All the experiments were conducted on a Picanol Omni-plus air jet loom, Model 2001. The loom was thoroughly checked for any air leakage before starting experimentation. Cotton yarn of 40 Ne was used as warp. The properties of weft yarns used in the study are given in *Table II*. The combinations of factor levels along with the air consumption value for each individual experimental trial are given in *Table III*. Fabric samples with 108 ends/inch, 84 picks/inch and plain weave design were produced in all the experimental trials.

TABLE I. Experimental factors and their levels.

Sr. No.	Factor	Factor symbol	Factor levels			
			1	2	3	4
1	Weft yarn count (Ne)	X_1	10	20	40	80
2	Fabric width (inches)	X_2	63	95	120	
3	Loom speed (rpm)	X_3	450	550	650	
4	Reed count (dents/inch)	X_4	16	28.75	53.5	

TABLE II. Properties of weft yarns.

Nominal count (Ne)	10	20	40	80
Actual count (Ne)	10.25	20.2	40.22	80.16
Count lea strength product	2516	2593	2904	3995
Twist Multiplier	4.05	3.74	4.52	4.02
CV_m %	9.10	11.9	10.75	10.84
Thin places -50% /km	0	13	3	9
Thick places +50%/ km	276	132	64	27
Neps +200%/ km	130	204	78	133
Hairiness index	12.30	8.16	4.50	3.07

TABLE III. Compressed air consumption at different levels of variables.

Sr. No.	X_1	X_2	X_3	X_4	Air consumption, (liters/sec)
1	10	63	450	16.00	14.3
2	10	63	450	28.75	14.1
3	10	63	450	53.50	13.8
4	10	63	550	16.00	15.0
5	10	63	550	28.75	14.8
6	10	63	550	53.50	14.6
7	10	63	650	16.00	15.8
8	10	63	650	28.75	15.6
9	10	63	650	53.50	15.5
10	10	95	450	16.00	22.6
11	10	95	450	28.75	22.1
12	10	95	450	53.50	19.6
13	10	95	550	16.00	24.1
14	10	95	550	28.75	23.5
15	10	95	550	53.50	20.3
16	10	95	650	16.00	25.5
17	10	95	650	28.75	24.8
18	10	95	650	53.50	21.8
19	10	120	450	16.00	29.3
20	10	120	450	28.75	29.1
21	10	120	450	53.50	28.8
22	10	120	550	16.00	30.8
23	10	120	550	28.75	30.5
24	10	120	550	53.50	30.0
25	10	120	650	16.00	32.3
26	10	120	650	28.75	31.8
27	10	120	650	53.50	31.1
28	20	63	450	16.00	14.0
29	20	63	450	28.75	13.8
30	20	63	450	53.50	13.5
31	20	63	550	16.00	14.7
32	20	63	550	28.75	14.5
33	20	63	550	53.50	14.3
34	20	63	650	16.00	15.3
35	20	63	650	28.75	15.1
36	20	63	650	53.50	15.0
37	20	95	450	16.00	22.3
38	20	95	450	28.75	21.3
39	20	95	450	53.50	18.6
40	20	95	550	16.00	23.8
41	20	95	550	28.75	22.8
42	20	95	550	53.5	19.8
43	20	95	650	16.00	25.1
44	20	95	650	28.75	24.3
45	20	95	650	53.50	21.3
46	20	120	450	16.00	29.0
47	20	120	450	28.75	28.8
48	20	120	450	53.50	27.0
49	20	120	550	16.00	30.5
50	20	120	550	28.75	30.1
51	20	120	550	53.50	28.5
52	20	120	650	16.00	32.0
53	20	120	650	28.75	31.5
54	20	120	650	53.50	30.6
55	40	63	450	16.00	13.7
56	40	63	450	28.75	13.5
57	40	63	450	53.50	13.1
58	40	63	550	16.00	14.3
59	40	63	550	28.75	14.1
60	40	63	550	53.50	14.0
61	40	63	650	16.00	15.0
62	40	63	650	28.75	14.8
63	40	63	650	53.50	14.6
64	40	95	450	16.00	21.8
65	40	95	450	28.75	20.8

66	40	95	450	53.50	18.3
67	40	95	550	16.00	23.5
68	40	95	550	28.75	22.3
69	40	95	550	53.50	19.3
70	40	95	650	16.00	24.6
71	40	95	650	28.75	23.8
72	40	95	650	53.50	20.8
73	40	120	450	16.00	28.6
74	40	120	450	28.75	28.5
75	40	120	450	53.50	26.6
76	40	120	550	16.00	30.1
77	40	120	550	28.75	29.8
78	40	120	550	53.50	28.1
79	40	120	650	16.00	31.6
80	40	120	650	28.75	31.2
81	40	120	650	53.50	30.1
82	80	63	450	16.00	13.5
83	80	63	450	28.75	13.3
84	80	63	450	53.50	13.0
85	80	63	550	16.00	14.1
86	80	63	550	28.75	13.8
87	80	63	550	53.50	13.8
88	80	63	650	16.0	14.8
89	80	63	650	28.75	14.6
90	80	63	650	53.50	14.5
91	80	95	450	16.00	21.6
92	80	95	450	28.75	20.5
93	80	95	450	53.50	17.8
94	80	95	550	16.00	23.3
95	80	95	550	28.75	22.0
96	80	95	550	53.50	19.0
97	80	95	650	16.00	24.3
98	80	95	650	28.75	23.5
99	80	95	650	53.50	20.4
100	80	120	450	16.00	28.5
101	80	120	450	28.75	28.3
102	80	120	450	53.50	25.83
103	80	120	550	16.00	29.8
104	80	120	550	28.75	29.6
105	80	120	550	53.50	26.6
106	80	120	650	16.00	31.5
107	80	120	650	28.75	31.0
108	80	120	650	53.50	27.5

RESULTS AND DISCUSSION

The statistical analysis was performed according to response surface methodology (RSM) using Minitab®16 statistical software package. The response surface method is a valuable tool for understanding the quantitative relationship between multiple input variables and one or more response variables. The analysis of variance (ANOVA) of response surface regression is given in *Table IV*. P-values of 0.000 indicate significant linear, square and interaction effects of the selected variables on the response variable (air consumption). The response surface regression coefficients are given in *Table V*. Only the terms with P-values less than 0.05 were considered statistically significant with 95% confidence level. Terms with P-values greater than 0.05, were excluded from the statistical model. The effect of factors on response can be directly estimated from the coefficient values which show that how much each factor contributes to the response. It is obvious from the coefficient values given in *Table V* that fabric width has the greatest effect on the air consumption, followed by loom speed, reed count and weft yarn count respectively. The final regression equation/model which can be used to predict the air consumption on air-jet loom by using uncoded/actual values of predictor variables is given as follows:

$$\begin{array}{ll}\text{Compressed Air Consumption} & = 6.10770 - 0.0346718\ X_1 + 0.0155271\ X_2 - 0.000147579\ X_3 + 0.0365014\ X_4 + 0.000312117\ X_1^2 \\ \text{(Liters/second)} & \quad + 0.00114788\ X_2^2 - 0.000338015 X_1\ X_4 + 0.000127147\ X_2\ X_3 - 0.000858253\ X_2\ X_4\end{array}$$

TABLE IV. Analysis of variance for air consumption.

Sr. No.	Source	DF	Seq SS coefficient	Adj SS	Adj MS	F	P
1	Regression	9	4404.24	4404.24	489.36	1224.97	0.000
2	Linear	4	4362.58	4251.48	1062.87	2660.59	0.000
3	Square	2	22.69	22.69	11.35	28.40	0.000
4	Interaction	3	18.98	18.98	6.33	15.84	0.000
5	Residual Error	98	39.15	39.15	0.40		
6	Total	107	4443.39				

TABLE V. Regression coefficients of air consumption by response surface analysis (coded units).

Sr. No.	Terms	Coefficients	SE coefficient	T	P
1	Constant	20.5390	0.14666	140.049	0.000
2	X_1	-0.6415	0.08084	-7.935	0.000
3	X_2	7.5723	0.07510	100.834	0.000
4	X_3	1.1486	0.07458	15.401	0.000
5	X_4	-1.0732	0.07615	-14.094	0.000
6	X_1^2	0.3823	0.15126	2.528	0.013
7	X_2^2	0.9324	0.13132	7.100	0.000
8	$X_1 X_4$	-0.2218	0.09563	-2.320	0.022
9	$X_2 X_3$	0.3624	0.09100	3.982	0.000
10	$X_2 X_4$	-0.4586	0.08949	-5.125	0.000

S = 0.632050 R-Sq = 99.12% R-Sq(pred) = 98.91% R-Sq(adj) = 99.04%

The effect of different factors on the compressed air consumption is discussed below.

Effect of Weft Yarn Count on Air Consumption

Surface plots depicting the effect of weft yarn count on air consumption are given in *Figure 1*. It is clear that air consumption increases as the weft yarn count becomes coarser. The effect of yarn count on air consumption was found to be statistically significant (regression coefficient -0.6415, P-value 0.000, *Table V)*. This may be explained by the fact that as the yarn count becomes coarser, it becomes heavier due to increase in yarn mass so more energy or the amount of air is required to carry it for insertion through the opening shed resulting in an increase of air consumption.

Effect of Reed Count on Air Consumption

It can be observed from *Figure 1* that air consumption decreases with the increase in reed count (negative relationship). These findings may be attributed to the fact that less space will be available for air to disperse through the dents as the reed count increases and vice versa.

Effect of Fabric Width on Air Consumption

The effect of fabric width on air consumption is shown in *Figure 2*. It is obvious that as the fabric width on loom increases, the air consumption increases. The fabric width is the most significant factor affecting the air consumption (regression coefficient 7.5723 and P-value 0.000, *Table V*). The fabric width actually means the distance that the weft yarn has to travel through the shed. When the fabric width is larger, the weft yarn has to travel a larger distance thus increasing the air requirement.

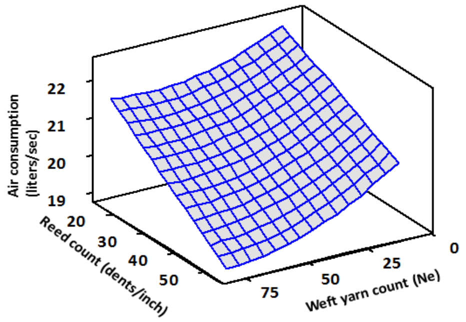

FIGURE 1. Effect of reed count and weft yarn count on compressed air consumption

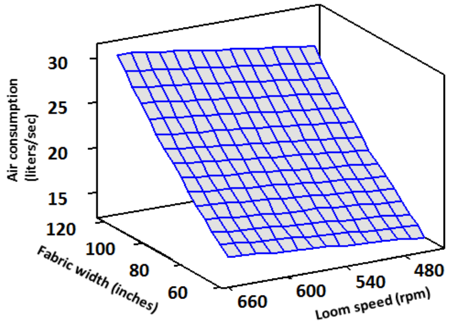

FIGURE 2. Effect of fabric width and loom speed on compressed air consumption.

Effect of Loom Speed on Air Consumption

Figure 2 depicts the effect of loom speed on air consumption. It is clear that air consumption increases with the increase in loom speed and shows a linear relationship. Loom speed is the second most significant factor affecting the air consumption (regression coefficient 1.1486 and P-value 0.000, *Table V*). The increase in air consumption with the increase in loom speed lies in the fact that more picks have to be inserted through the shed per unit time by the compressed air so the requirement of air per unit time will be more.

Validation of Prediction Model

In order to check the validity of the developed model, some extra experiments were performed by selecting the combinations of values of input variables according to *Table VI*. A comparison of actual air consumption values and those predicted by the developed model is shown in *Table VII*. *Figure 3* gives the fitted line plot between the actual air consumption and the predicted air consumption values by the developed model. The Pearson correlation between the actual and the predicted air consumption was found to be 0.993 with a P-value of 0.000 indicating a very strong ability and accuracy of the prediction model.

TABLE VI. Factor values for model validation.

Sr. No.	Weft count (Ne)	Fabric width (inches)	Loom speed (rpm)	Reed count (dents/inch)
1	40	114	550	53.5
2	14	114	450	44.5
3	16	63	650	31.25
4	40	105	600	42.9
5	20	75	650	31.25
6	40	89	650	36.5

TABLE VII. Actual and predicted air consumption.

Sr. No.	Actual (L/s)	Predicted (L/s)	Diff. (%)
1	25	25.7940893	-3.176357
2	25.8	25.8874496	-0.338952
3	15.6	15.5597151	0.25824
4	25.4	25.3396983	0.23741
5	19.1	18.1808371	4.81237
6	20.6	21.0047765	-1.964935

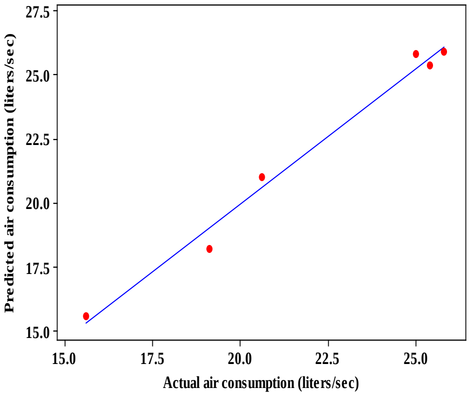

FIGURE 3. Fitted line plot between the predicted and actual air consumption.

CONCLUSION

The air consumption on air-jet loom may vary from 13 to 40 liters/second depending on weft yarn count, fabric width, loom speed and reed count. The air consumption increases as the fabric width and loom speed increases and decreases as the weft yarn count and reed count increases. Fabric width is the most dominant factor affecting the air consumption. Statistical model for predicting the air consumption on air jet loom was developed. The prediction ability and accuracy of the developed model was assessed by the correlation analysis of the predicted and actual air consumption values. The analysis showed a very strong ability and accuracy of model for predicting the air consumption on air jet loom.

ACKNOWLEDGEMENT

The authors would like to thank Mr. Zahid Rafique Mills Manager Be Be Jan Colors Limited (Weaving Unit) for his cooperation and support during experimentation.

REFERENCES

[1] Ye, G.; Shen, D.; "Study on Pneumatic Weft Insertion Behaviour in Main Nozzle," Fibres & Textiles in Eastern Europe, vol. 15, 2007, p. 63.

[2] Koç, E.; Çinçik, E.; "Analysis of energy consumption in woven fabric production," Fibres & Textiles in Eastern Europe, vol. 18, 2010, p. 79.

[3] Masuda, A.; Sogi, Y.; Ogata, N.; "Efficiency of an Accelerating Apparatus for Weft Yarn Insertion of Air Jet Loom," Journal of the Textile Machinery Society of Japan, vol. 52, 1999, pp. T9-T17.

[4] Ishida, M.; Okajima, A.; "Flow Characteristics of the Main Nozzle in an Air-Jet Loom Part I: Measuring Flow in the Main Nozzle," Textile Research Journal, vol. 64, 1994, pp. 10-20.
[5] Ishida, M.; Okajima, A.; "Flow Characteristics of the Main Nozzle in an Air-Jet Loom Part II: Measuring High Speed Jet Flows from the Main Nozzle and Weft Drag Forces," Textile Research Journal, vol. 64, 1994, pp. 88-100.
[6] Jeong, S. Y.; Kim, K. H.; Choi, J. H.; Lee, C. K.; "Design of the Main Nozzle with Different Acceleration Tube and Diameter in an Air-Jet Loom," International Journal of the Korean Society of Precision Engineering, vol. 6, 2005, pp. 23-30.
[7] Göktepe, Ö.; Bozkan, Ö.; "Study on reduction of air consumption on air-jet weaving machines," Textile Research Journal, vol. 78, 2008, pp. 816-824.
[8] Belforte, G.; Mattiazzo, G.; Testore, F.; Visconte, C.; "Experimental investigation on air-jet loom sub-nozzles for weft yarn insertion," Textile Research Journal, vol. 81, 2011, pp. 791-797.
[9] Krause, H. W.; "The air-jet weaving machine in practical use," Melliand Textilberichte (Eng. Ed.), September, 1980.
[10] Wahhoud, A.; "Investigation into the behavior of yarns in pneumatic weft insertion," Melliand Textilberichte (Eng. Ed.), April, 1983.
[11] Kissling, U.; "Experimental and theoretical analysis of weft insertion by air-jet," Melliand Textilberichte (Eng. Ed.), February, 1985.
[12] Githaiga, J.; Vangheluwe, L.; Kiekens, P.; "Relationship between the Properties of Cotton Rotor Spun Yarns and the Yarn Speed in an Air-jet Loom," Journal of the Textile Institute, vol. 91, 2000, pp. 35-47.
[13] Kayacan, M. C.; Dayik, M.; Colak, O.; Kodaloglu, M.; "Velocity control of weft insertion on air jet looms by fuzzy logic," Fibres & Textiles in Eastern Europe, vol. 12, 2004, p. 47.

AUTHORS' ADDRESSES

Abdul Jabbar
Shakeel Ahmed
Tanveer Hussain, PhD
Noman Haleem
Faheem Ahmed
National Textile University
Sheikhupura Road
Faisalabad, Punjab 37610
PAKISTAN