Modeling the Feeding Process in Gill-Box Using Non-Linear Mass-Spring System

Vajiha Mozafary and Pedram Payvandy

***Abstract*— The purpose of this study is to investigate the behavior of the sliver pick-up from can in gill-box machines during feeding process. A model is presented to predict the height changes of can plate during the feeding process. To this aim, a mass-spring model is introduced. The behavior of the can plate is considered as linear spring system and the sliver weight in the can is also noted as time depended mass value. The mass spring derived equations are solved using Three-order Straight Forward Expansion method. Result of can plate height predicting by the model is compared to some experimental data which are collected from a wool yarn mill. The meaningful 12 percent difference between proposed model and the experimental value proves the acceptable result of desired model that can be used for predicting the height of can plate by the aim of machine speed and sliver count.**

Key words: Can, gill-box, mass-spring model, straight forward expansion

I. INTRODUCTION

Sliver evenness has strong influence on the yarn quality. One of the most important factors that affect on sliver evenness is machine adjustment and feeding process. In the earlier works, Taylor, Grosberg, Audivert and Vidiella, Sengupta and Kapoor and Cherif and his coworkers studied on the influence of delivery speed on the fiber behavior in the drafting zone to explain the sliver quality parameters [1-5]. Ernst *et al.* as well as Cherif and Wulfhorst observed that at high draw frame speed, the degree of fiber parallelization obtained in the draw frame decreases [6-7]. Ishtiaque *et al.* investigated draw frame delivery speed, card machine draft and card machine coiler diameter at card have strong influence on the fiber orientation parameters of the sliver [8].

Sliver feeding parameters effect on the quality of sliver as well as draw frame machine adjustment. Sliver feeding parameters can be defined as:
Distance between can and draw frame,
Can edge smoothness, and
Can plate height during sliver feeding process.

All of these parameters effect on feeding sliver quality and the evenness of produced sliver. Two first parameters can be easily checked and adjusted while the distance between sliver in the can and machine feeding zone should be fixed when can is full till empty. For this purpose, can plate position should be changed according to machine feeding speed and sliver count. To achieve this goal, the can spring stiffness should be determined.

In this paper a model base of mass spring system is introduced to predict can plate position by considering the can spring stiffness, machine speed in feeding zone and the sliver count. The suggested model can be applied to select can spring stiffness in yarn manufactory.

V. Mozafary and P. Payvandy are with the Department of Textile Engineering of Yazd University, Yazd, Iran. Correspondence should be addressed to P. Payvandy (e-mail: peivandi@yazd.ac.ir).

II. MODELING

In order to simulate the behavior of the sliver pick-up from can in gill-box machines, a model consists of a mass and a linear spring was introduced in a manner that the can plate behavior was supposed as linear spring system and the amount of sliver in can in feeding process considered as a time-variable mass system. The schematic of proposed model is illustrated in Figure 1.

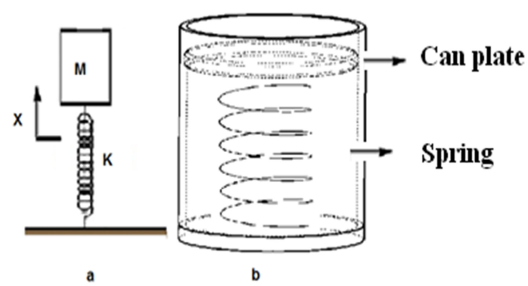

Fig. 1. a) The proposed model for predicting of height changes of can plate during feeding process of sliver from can. b) Can structure

A. Assumptions

In order to simplify the model, some assumptions were made:
i- The spring behavior was assumed to be linear,
ii- Mass was expected to be concentered, and
iii- The removal of sliver from can was supposed to be uniform.

B. Model analysis

As mentioned the model is consisted of a mass and a linear spring. Equation 1 shows the employed equation of motion.

$$M\ddot{X} + KX = Mg \qquad (1)$$

where, M is the mass of can plate with amount of sliver in above it, X shows the displacement of can plate, $\ddot{X}$ demonstrates the acceleration of can plate, g is gravity acceleration and K shows the stiffness coefficient of spring. It should be noted that the amount of sliver is reduced by feeding it to the gill-box machine. So M is a time variable parameter and can be written as:

$$M = m - \tilde{m}(t) \tag{2}$$

where m shows the mass of can plate and $\tilde{m}(t)$ demonstrates the mass of sliver which is time dependent and can be defined by Equation 3.

$$\tilde{m}(t) = a \times t \tag{3}$$

where a is depend on speed machine and can be computed from Equation 4 while t denotes time.

$$a = \frac{\text{Sliver density} \times \text{Feeding speed}}{60 \times 1000} \tag{4}$$

By considering

$$\overline{X} + x = X \tag{5}$$

where $\overline{x}$ is the initial static equilibrium position and x is position of can plate considering the initial static equilibrium position, as is shown in Figure 2

$$k\overline{x} = mg \tag{6}$$

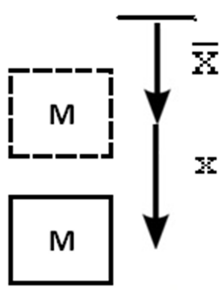

Fig. 2. Mass center position.

Equation (7) can be obtained by substituting Equation (5) into Equation (1).

$$M\ddot{x} + K(x + \overline{x}) = Mg \tag{7}$$

Then, Equation (8) can be derived by substituting Equations (2) and (3) into Equation (7).

$$(m - a \times t)\ddot{x} + K(x + \overline{x}) = (m - a \times t)g \tag{8}$$

Later, Equation (9) can be obtained by dividing the two sides of Equation (8) by (m).

$$\left(1 - \frac{a}{m}t\right)\ddot{x} + \frac{K}{m}(x + \overline{x}) = \left(1 - \frac{a}{m}t\right)g \tag{9}$$

Finally, by substituting Equation (6) into Equation (9), Equation (10) could be derived.

$$\left(1 - \frac{a}{m}t\right)\ddot{x} + \frac{K}{m}x = -\frac{a}{m}tg$$

For simplification, new parameters (α and γ) are introduced as follows:

$$\alpha = \frac{a}{m} \tag{11}$$

$$\gamma = \frac{a}{m}g \tag{12}$$

Besides, ω_n is considered as natural frequency of the linear system, as shown by Equation (13).

$$\omega_n^2 = \frac{K}{m} \tag{13}$$

By considering Equation (12), Equation (9) can be written:

$$(1 - \alpha t)\ddot{x} + \omega_n^2 x = -\gamma t \tag{14}$$

Straight Forward Expansion method was then used to solve Equation (14) [9]. To solve this equation, new parameters, i.e. β and λ, could be defined as:

$$\beta = \frac{\alpha}{\varepsilon^2} \tag{15}$$

$$\lambda = \frac{\gamma}{\varepsilon^2} \tag{16}$$

Equation (17) can be obtained by substituting Equations (15) and (16) into Equation (14).

$$(1 - \varepsilon^2 \beta t)\ddot{x} + \omega_n^2 x = -\lambda \varepsilon^2 t \tag{17}$$

where, ε is perturbation parameter.

The solution is assumed to be in the form of an infinite series of the perturbation parameter ε which could be represented as Equation (18).

$$x(t) = \varepsilon x_1(t) + \varepsilon^2 x_2(t) + \varepsilon^3 x_3(t) + \ldots \tag{18}$$

In this study, the third-order perturbation method was used to solve the differential equation, therefore the response of vibration could be considered as:

$$x(t) = \varepsilon x_1(t) + \varepsilon^2 x_2(t) + \varepsilon^3 x_3(t) \tag{19}$$

Then, Equation (20) can be obtained by substituting Equation (19) into Equation (17).

$$(1 - \varepsilon^2 \beta t)(\varepsilon \ddot{x}_1 + \varepsilon^2 \ddot{x}_2 + \varepsilon^3 \ddot{x}_3) + \omega_n^2(\varepsilon x_1 + \varepsilon^2 x_2 + \varepsilon^3 x_3) = -\lambda \varepsilon^2 t \tag{20}$$

Since the perturbation parameter ε could have been chosen arbitrarily, the coefficients of the various powers of ε must be equated to zero. This leads to a system of equations which can be solved successively:

$$\varepsilon^1 : \ddot{x}_1 + \omega_n^2 x_1 = 0 \tag{21}$$

$$\varepsilon^2 : \ddot{x}_2 + \omega_n^2 x_2 = -\lambda t \tag{22}$$

$$\varepsilon^3 : \ddot{x}_3 + \omega_n^2 x_3 = +\beta t \ddot{x}_1 \tag{23}$$

To solve Equation (21), x_1 is considered as follow:

$$x_1 = C \sin(\omega_n t + \varphi_0) \tag{24}$$

The coefficients C and φ_0 can be calculated by the initial conditions $x_0(t) = 0$ and $x'_0(t) = 0$. To solve Equation (22), x_2 could be considered as follow:

$$x_2 = -\frac{\lambda}{\omega_n^2}t \tag{25}$$

Then, Equation (26) can be obtained by substituting Equation (24) into Equation (23).

$$x_3 = \frac{C\omega_n \beta}{2}\cos(\omega_n t + \varphi_0) \tag{26}$$

By substituting Equations (24) to (26) into Equation (19), the response of the system could be obtained as follows:

$$x = \varepsilon C \sin(\omega_n t + \varphi_0) - \frac{\lambda \varepsilon^2}{\omega_n^2}t - C\varepsilon^3 \omega_n \beta \cos(\omega nt + \varphi_0) \tag{27}$$

Equation (28) can be obtained by considering $\varepsilon C = A$.

$$x = A\sin(\omega_n t + \varphi_0) - \frac{\gamma}{\omega_n^2}t + \frac{A\omega_n}{2}\cos(\omega_n t + \varphi_0) \qquad (28)$$

Now, to solve Equation (28) the initial conditions $x_0(t) = 0$ and $x'_0(t) = 0$ were supposed.

Equation (28) shows the height of can plate during sliver pick-up from can toward the equilibrium condition. By using the suggested model, the behavior of sliver pick-up of can could be predicated.

III. RESULT AND DISCUSSION

A. *Study of model accuracy*

In order to investigate the model precision in comparison with experimental result, four gill-box machines in a domestic worsted mill have been selected. Table I illustrates feeding speed, average of sliver density and sliver length in can for each machine.

TABLE I
SLIVER AND GILL-BOXES PROPERTIES

Machine No.	Feeding speed (m/min)	sliver density average (gram/meter)	Sliver length in can (meter)	Sliver weight in can (length×[gram/meter])
Gill-box 1	230	22	1200	26.4
Gill-box 2	250	21	1200	25.2
Gill-box 3	235	10	2000	20
Gill-box 4	210	5	2500	12.5

Model parameters are shown in Table II. The parameters were extracted from the data illustrated in Table I.

TABLE II
MODEL PARAMETERS

Machine No.	Initial mass Sliver weight in can+ plate weight of can (Kg)	spring stiffness coefficient [K] (N/m^2)	Mass changes coefficient [a] (Kg)
Gill-box 1	29.4	15	0.084
Gill-box 2	28.2	15	0.087
Gill-box 3	23	15	0.039
Gill-box 4	15.5	15	0.017

Spring elongation of can was measured under a constant force to determine spring stiffness of each can. Then spring stiffness coefficient was calculated by considering Equation (29).

$$F = K \times \Delta X \qquad (29)$$

In Equation (29) K is spring stiffness coefficient (Newton/meter), F is force (Newton) and ΔX is elongation (meter).

In order to study of model accuracy, height of can plate during sliver pick-up from can for each Gill-box were measured. Table 3 shows the comparison between result of model and experimental.

The difference between model prediction and the experimental measurements are shown in Table III, while the error of model is illustrated in this table too. Differences can be due to following reasons:

i- The spring behavior was assumed to be linear in model,
ii- Mass was thought to be concentered, and
iii- Some types of errors occurred during experimental Measurement.

B. *Can spring stiffness determining*

As it mentioned earlier, distance between sliver in the can and machine feeding zone is one of the important parameters on sliver quality. So, the pick-up height should be constant. To have a constant pick-up height, the can plate must rise as same height as sliver decreases. Therefore, can plate position should be change according to machine feeding speed and sliver count. Hence, the can plate changes should depend on the spring stiffness. For this reason, the optimal value of spring stiffness was determined by the suggested model in this research.

TABLE III
COMPARISON BETWEEN MODEL AND EXPERIMENTAL RESULTS

Machine No.	Time (minute)	Can plat height (result of model) (cm)	Can plat height (experimental) (cm)	Error (%)
Gill-box 1	1	3.3	2.7	22
	2	6.7	5.8	15
	3	10.08	9	12
	4	13.45	12.5	7
	5	17.1	16.1	6.2
Gill-box 2	1	3.48	3.1	12
	2	6.96	6.4	8.7
	3	10.44	9.2	13.4
	4	13.93	12.9	7.9
	5	17.4	15.8	10.1
Gill-box 3	2	3.12	2.7	15.5
	4	6.24	6.6	11.4
	6	9.37	8.6	8.9
	8	11.6	10.7	8.4
Gill-box 4	2	1.36	1.2	13.3
	4	2.72	2.4	13.3
	6	4.08	3.7	10.2
	8	5.44	5	8.8
	10	6.8	6.1	11.4
	12	7.6	6.8	11

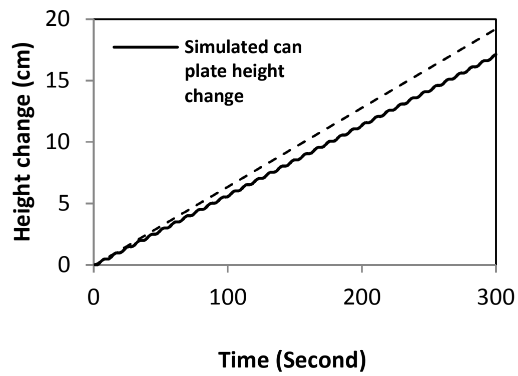

Fig. 3. Comparison between time responses of the presented model for can plate height changes of gill-box 1 and sliver height change during the sliver pick-up from ca.

TABLE IV
DIFFERENCE BETWEEN SLIVER HEIGHT AND HEIGHT OF CAN PLATE

Machine No.	Model of machine	Time (minute)	Height of can plate (cm)	Sliver height (cm)	Error (%)
Gill-box 1	GC15-Schlumber(2000)	1	3.3	3.84	14
		2	6.7	7.68	13
		3	10.08	11.52	12
		4	13.45	15.36	12
		5	17.1	19.2	10
Gill-box 2	GC15-Schlumber(2000)	1	3.48	3.84	9
		2	6.96	7.68	9
		3	10.44	11.52	9
		4	13.93	15.36	9
		5	17.4	19.2	9
Gill-box 3	GC15-Schlumber(2000)	2	3.12	4	22
		4	6.24	8	22
		6	9.37	12	22
		8	11.6	16	27
Gill-box 4	GC15-Schlumber(2000)	2	1.36	1.66	27
		4	2.72	3.33	18
		6	4.08	4.96	17
		8	5.44	6.57	17
		10	6.8	8.19	16
		12	7.6	10	24

Height of can plate over the time can be calculated through Equation (28). For calculation of sliver height during time, it was assumed that the change of sliver height is linear. With this assumption, the change coefficient of sliver height could be determined by Equation 30.

$$\text{Change coefficient of sliver height} = \frac{\text{Initial height of silver into can}}{\text{Feeding time}} \quad (30)$$

It is clear from Figure 3 that the sliver height in can is more than the height of can plate (pick-up height is not constant). The difference between sliver height and height of can plate is illustrated in Table IV.

Table IV shows that sliver pick-up height of can is not constant, that can cause sliver stretch as well as unevenness during the sliver pick-up. This study attempted to decrease the unevenness of sliver by determining optimal value of spring stiffness parameter (K) of each gill-box. Parameter K is calculated by using Equations (27) and (29) in a manner that can plate height was adjusted based on machine speed and sliver count. The optimized and experimental values of spring stiffness coefficient for each gill-box are shown in Table V.

TABLE V
OPTIMIZED VALUE OF SPRING STIFFNESS COEFFICIENT (K)

Machine No.	Experimental value of spring stiffness coefficient [K] (N/m^2)	Optimized value of spring stiffness coefficient [K] (N/m^2)
Gill-box 1	15	13.12
Gill-box 2	15	13.58
Gill-box 3	15	10.85
Gill-box 4	15	12

Table VI illustrates the comparison between time responses of the presented model for can plate height changes with optimized value of spring stiffness coefficient (K) and the sliver height change during the feeding process.

TABLE VI
DIFFERENCE BETWEEN SLIVER HEIGHT AND HEIGHT OF CAN PLATE WITH OPTIMIZED VALUE OF SPRING STIFFNESS COEFFICIENT

Machine No.	Model of machine	Time (minute)	Height of can plate with optimized value of spring stiffness coefficient (cm)	Sliver height (cm)	Error (%)
Gill-box 1	GC15-Schlumber(2000)	1	3.82	3.84	0.5
		2	7.71	7.68	0.3
		3	11.51	11.52	0.08
		4	15.31	15.36	0.3
		5	19.2	19.2	0
Gill-box 2	GC15-Schlumber(2000)	1	3.81	3.84	0.08
		2	7.65	7.68	0.03
		3	11.49	11.52	0.02
		4	15.38	15.36	0.01
		5	19.2	19.2	0
Gill-box 3	GC15-Schlumber(2000)	2	4.1	4	0.02
		4	8	8	0
		6	11.8	12	0.1
		8	15.7	16	0.1
Gill-box 4	GC15-Schlumber(2000)	2	1.65	1.66	0.06
		4	3.31	3.33	0.06
		6	4.98	4.96	0.04
		8	6.59	6.57	0.03
		10	8.23	8.19	0.04
		12	10.2	10	0.2

As it is illustrated in Table VI, by using optimized value of spring stiffness coefficient, the height of sliver in can becomes about same with height of can plate (pick-up height is constant). Therefore the amount of stretch and unevenness of sliver can be reduced by selecting the appropriate value for spring stiffness coefficient of can. It is no doubt that the computation should be done on two factors, i.e. machine specifications and sliver properties.

IV. CONCLUSIONS

In this study, sliver pick-up behavior of can was investigated. A model base of mass spring system was introduced to predict the can plate position by considering can spring stiffness, machine speed in feeding zone and sliver count. Model was analyzed for gill-box cans in a worsted mill to gain higher accuracy. Results of the model were compared with experimental data and a significant 12% difference was observed between can plate height predicted by the model and the experimental results. It was also observed that the sliver height in can is more than height of can plate (pick-up height is not constant) therefore, to have a constant pick-up operation the spring stiffness should be determined by considering machine speed and sliver properties. Spring stiffness was determined according to machine specifications and sliver properties for each gill-box. It was observed that by selecting optimal value of spring stiffness parameter (K) of each gill-box, the height of the can plate become as same as sliver.

REFERENCES

[1] D. S. Taylor, "The velocity of floating fibres during drafting of worsted slivers", *J. Text. Inst*., vol. 50, no. 2, pp. 233-236, 1959.

[2] P. Grosberg, "A causes of irregularities in roller drafting", *J. Text. Inst*., vol. 52, no. 2, pp. 91-95, 1961.

[3] R. Audivert R and J. E. Vidiella, "The effect of speed of drafting, in terms of spindle speed, on skin breaking strength of cotton yarn spun on double apron system", *Text. Res. J*., vol. 32, no. 8, pp. 652-657, 1962.

[4] A. K. Sengupta and L. M. Kapoor, "Effect of drafting speed at ring frame on yarn strength and irregularities", *Text. Res. J*., vol. 43, no. 2, pp. 121-122, 1973.

[5] C. H. Cherif C H, G. Satlow G and B. Wulfhorst, "Sliver irregularities during drafting on worsted draw frames", *Melliand Textilberichte*, vol. 5, pp. 86-87, 2000.

[6] H. Ernest, G. Eng and H. Portman, "New generation of high speed draw frames parameters and industrial performance", *Textile Praxix International*, vol. 48, pp. ix-xi, 1993.

[7] C. H. Cherif and B. Wulfhorst, "Measurement techniques for analyzing sliver irregularity in high performance draw frame sliver guiding", *Melliand Textilberichte (English Ed.)*, vol. 7, pp. 139-141, 2001.

[8] S. M. Ishtiaque, A. Mukhopadhyay and A. Kumar, "Impact of high-speed draw frame and its preparatory on fibre orientation parameters at sliver", *J. Text. Inst*., vol. 98, no. 6, pp. 501-512, 2007.

[9] A. H. Nayfeh, and D. T. Mook, "*Nonloinear Oscillations*", New York: John Wiley and Sons, 51, 1995.