Theoretical Investigation of Separator Units in Saw-gin Machines.

I: Cotton Flow Rate Estimation

Abstract

This theoretical study is intended to investigate the performance of a saw-gin ginning machine with special reference to separator units. For this purpose, a theoretical model of the separator units of a particular saw-gin machine has been developed by introducing non-dimensional parameters defining the mechanical operating conditions, and we have also outlined a design procedure whereby the cotton flow rate and loss of cotton can be estimated in such a system. This paper forms part of an extended theoretical investigation into the separator units of saw gin machines; here, only the flow rate estimation results obtained for the first unit of the separator have been discussed.

Keywords: ginning process, saw-gin, separator units, non-dimensional flow rate.

Introduction

Ginning is the first effective process of cleaning and separating the impurities and seeds from the cotton. After the cotton has been picked, it is taken to the ginning-mills, where the fibre, called cotton lint in the trade, is separated from the seed. Ginning processes are important in determining the cotton fibre quality for the production of cotton yarn.

The measured and unmeasured cotton fibre properties may be identified as follows: length, strength, elongation, cleanliness/cleanability, fineness and maturity, sugar content, mutes, neps, fibre maturity, stickiness, contamination, seed coat fragments, dead cotton, cavitoma. The only characteristics influenced by the ginner are length, neps and foreign matter. Also, the fibre moisture during ginning, the amount of cleaning used and the gin housekeeping practices influence the cotton fibre’s characteristics [1].

Hughes reviewed the ginning literature for saw-gin and roller-gin machines. Lint cleaners are very important in determining the quality of cotton. Lint weight, mean length, short fibres, neps and yarn strength are influenced by lint cleaners. The effect of lint cleaners can be summarised as follows: card web nep counts, short fibre content and dyeing problems may increase; yarn appearance, staple length and strength decrease as the amount of lint cleaning increases. [2].

Ginning mills are divided into saw-gin mills and roller-gin mills. The processed cotton is named after the looms used, thus saw-gin cotton or roller-gin cotton. The working principles of these two machines are different from each other.

In general, the structure of the roller-gin machine is rather simple. However, labour expenses are much more than those of saw-gin machines, as these are more complex than roller-gin machines. Harmancioğlu found in his investigations that saw-gin cotton was more suitable for spinning coarse yarn, and roller-gin cotton was suitable for finer yarns. These two ginning processes have little effect on the strength of the yarn [3].

The roller gin is a slow working machine and processes 60 to 80 kg of seed cotton per hour. However, saw gins can process 600-800 kg per hour. Roller-gin machines have minimal pre-cleaning equipment, and the lint contains leaf and trash. Saw-gin machines, on the contrary, have a great deal of pre-cleaning equipment for seed cotton and lint cleaners after cleaning [4].

It is very difficult to estimate the cost of ginning, and data on ginning costs is not available from all the cotton producing countries. However, Chaudhry [5] considered the cost of ginning in many countries in the light of the transportation cost to the ginning factory, the fee for classing and grading the cotton, and the cost of other expenses related to ginning. It was shown that the ginning cost was highest in Spain, at US$549 per ton of lint, whereas the lowest cost was in China, at US$25 per ton of lint. The mean value of ginning cost in selected countries was US$240.

Mangialardi & Anthony discussed the characteristics and efficiency of flow-through air-type lint cleaners. It was mentioned that improved air-type lint cleaners, by adding a second stage of saw-type lint cleaning, might be sufficient for lint cleaning with one saw cylinder lint cleaner [6]. Kechagia [7] has outlined the conditions and requirements to be met in quality cotton production as well as the relevant practices in examining the optimisation of the ginning process. Several recommendations for better ginning operations in cotton procedures and for industry-government organisations were also made.

Chaudhry [5] also examined the existing number of saw-gin and roller-gin looms used worldwide. The roller-gin and saw-gin looms in selected cotton producing countries were investigated. According to the paper, India has the most roller-gin looms with 46,529 looms and the USA leads in using saw-gin looms, with 1275. The distribution of ginning cotton systems in selected countries in percentages has also been investigated by Chaudhry, concluding that saw-gin ginning machines were slightly more preferred to roller-gin machines. Doraiswamy et al. examined the roller gin and saw gin machines, and their characteristic differences & process stages in detail [8]. Both ginning operations include pre-ginning equipments and lint cleaners. The aim is to condition, clean and prepare the seed cotton before ginning. The feed rate of seed cotton from the separator to the ginning machine influences the lint produced. The saw or roller speed also influences the quality of lint produced.

In saw-gin ginning machines, the cotton fibre is separated by the saw, instead of the roller in the roller-gin machine. Saw-gins are divided into air blast gin and brush gin according to the type of the stripper. The brush-type ginning machine is preferred in high-capacity machines [9]. Further studies were carried out elsewhere by introducing general desc-
riptive information on ginning process and ginning machinery [10,11]. A theoretical examination of ginning machines has been carried out by Yatçı [12]. In this study, saw-gin and roller-gin ginning machines were analysed theoretically, and flow, moment and mass equations of the separator and cleaners were utilised. Some of the findings concerning the theoretical approach mentioned above have been presented by Koç and Yatçı [13,14].

A typical saw-gin machine is shown in Figure 1. The ginning machine has usually principal parts. These are the cleaning unit (A), the seed cotton collecting unit (B), the ginning process unit (C), the unit for taking up fibre from the saw (D), the seed carrying unit (E), the unit carrying impurities (F) and the body of the machine (G). Seed cotton is carried from the feeder to the cleaning unit of the saw-gin ginning machine. This unit consists of a huller rib (4), a rotating brush (1) and a roller-saw (3) that separates the impurities in seed cotton and continuously feeds the saws (6).

The seed cotton is carried to the ginning zone (through the main ribs (5) and saws (6)) by the rotating brush (1). The separated impurities are removed by the helical carrier (9) from the machine. The fibres, separated from their seeds, are carried to unit D on the saw teeth. This unit contains a rolling-brush (7). The brush, rotating in a counter-clockwise direction, strips the fibres on the saw and moves them to the exit of the machine. The seeds that cannot pass through the saw and the ginning ribs drop on to the seed-carrying helical unit (9), and are removed from the machine by the seed-carrying unit (E).

In this investigation, the saw-gin mill and saw-gin machine are briefly introduced. The separator and its units are examined in detail. The working principles of the separator, which affects the performance of the ginning machine, are analysed by the theoretical models developed, in which the non-dimensional system parameters are evaluated by these models. This study forms a part of a wider investigation into the mechanical design of separator units and their dynamic performance analysis in saw-gin ginning machines. Here, in this paper, a theoretical approach to analyse the performance of the separator units, as well as the mechanical design procedure of this unit, has been taken by considering the flow rate estimation.

The design principles of separators

A selected saw-gin mill generally consists of seven units. These units are the separator unit, the inclined pre-cleaner, the unit which transport pre-cleaned seed cotton, the feeding zone to the saw-gin, the saw-gin ginning machine, the seed and burr-carrying helical units and the cleaning unit ginned cotton. The separator unit carries the seed cotton to the saw-gin mill by a vacuum (air suction) from the store.

The main parts of the separator unit are shown in Figure 2. The seed cotton is transferred to the mill by vacuum created through an aspirator existed in the store. Since it is necessary to separate the air-cotton blends, the cotton is carried by vacuuming, and firstly transferred to the separator. In this way, air and dust are separated from the seed cotton. The separated dust is carried to the cyclone and the seed of the cotton is carried to the seed-cleaners by a vacuum under the separator. The main parts of the separator are the rotor, the perforated curved screen and the vacuum feeder below the screen.

The first unit (I) consists of a curved screen and rotating vanes fitted onto a rotor that has a certain running speed. Seed cotton is carried and wiped by the air flow through the wipers and curved screen. The impurities are separated from the seed cotton by being passed over the holes on the curved screen. The screen and the air flow are adjusted in such a way that this section is self-cleaning, or the action of the seed cotton flow keeps the section wiped clean. The second unit (II) connects the separator to the inclined pre-cleaner. In this unit, seed cotton is partially pressed and is carried to the first cleaners. The main differences between these separator units can be explained as follows:

1. The carrying of the seed cotton in the first unit occurs through the curved screen, half of which is perforated and over the tip of the wipers (vanes).
2. The seed cotton does not drop into the gaps between the successive vanes due to the presence of the air flow.

3. In the second unit, however, the seed cotton is carried in the volumes between the successive vanes towards the exit.

4. Additionally, the first unit is geometrically bigger than the second unit, and the rotor velocities of these units must be proportional to each other in order to maintain continuous seed-cotton feeding.

The seed cotton first enters the first unit of the separator by the air flow from the cotton suction line. The separator separates the air-cotton blends and dust. Seed cotton is moved from the first unit to the second unit, so each of the separator units should perform simultaneously, and a certain rate of angular speeds of two units should be determined.

**Theoretical analysis of the separator units**

The rate of cotton flow in the separator units is an important parameter for determining the optimum working conditions. The required rate of angular velocities and the mass flow rate of seed cotton carried in the system are determined in order to find out the optimum performance of the system. The volumetric flow rate in terms of the non-dimensional parameters in the first unit of the separator can be calculated by considering the theoretical estimation of cotton flow rate of separator unit have been separately investigated.

**Cotton Flow Rate Estimation of First Unit**

The main geometrical dimensions of the first separator unit are shown in Figure 3a. In this unit, seed cotton is carried by wiping in the radial clearance between the inner surface of the body and the outer radius of the wiper bars, as shown.

The seed cotton is not carried by the whole circumference of the carrier, since only by a portion of the circumference seed cotton can be carried actively. The cotton is removed around the tip of the carrier through a length of the partial circumference. This rate is defined as ‘k₁’ and numbers about 70-85% of the total circumference. Hence, the carried volume of seed cotton can be written as:

\[ V = k₁ \pi (r₂^2 - r₁^2) b₁ \]

where \( r₁ \) : the inner radius of the body, \( r₂ \) : the outer radius of the wiper bars, and \( b₁ \) is the width of the wiper or body.

The flow rate of cotton moving in the first unit of the separator can be calculated by considering this volume and the number of revolution per minutes of the rotor (n). The seed cotton flow rate may be found by defining ‘n’ in terms of angular velocity \( \omega \):

\[ Q₁ = 3000k₁ \pi (r₂^2 - r₁^2) b₁ \]

Because a wide range of application facilities and flexibility in design is provided, it is convenient to change this equation into a non-dimensional form. This may be done by defining the non-dimensional parameters in terms of the inner radius of the body as \( \bar{b} = b₁ / r₁ \) and \( \bar{r} = r₂ / r₁ \) and hence,

\[ \bar{Q}_1 = 30k₁ \pi (1 - \bar{r}^2) \bar{b} \]

This equation yields the non-dimensional seed cotton flow rate as, \( \bar{Q}_1 = Q₁ / \omega \).

**Cotton Flow Rate Estimation of Second Unit**

Figure 3b shows the theoretical model for the second unit of the separator. Since, in this unit, seed cotton is carried in the gap between the successive reels, the volume of the seed cotton carried is found by subtracting the volume of vane bars or reels from the whole volume between the inner and outer radius of the unit, namely \( r₁ \) and \( r₂ \) respectively.

The volume of a vane can be calculated by considering the thickness of a vane (t) and the width of the body (b₂) perpendicular to the running surface; if there are z pieces of vane on the revolving reel, the total volume may be found as,

\[ Vₚ = k₂ \pi (r₂^2 - r₁^2) b₂ \]

where \( k₂ \) is the coefficient matching with the effective portion of the seed-carrying circumference, and taken to be about 60-75%.

The flow rate of seed cotton is found by considering the rotor angular velocity. Changing this equation into a non-dimensional form yields the following:

\[ Q₂ = 30k₂ \pi b₂ \left( \frac{1 - \bar{r}^2}{1 - r₁ / r₂} \right) \]

where, \( i = 1 / r₁ \) and \( \bar{r} = r₂ / r₁ \) are the non-dimensional design parameters. The non-dimensional flow rate is defined as \( Q₂ = Q₂ / \omega \). and \( \omega \) indicates the product of the total thickness of the revolving reel and the number of vanes.

Since \( Q₁ \) and \( Q₂ \) are the non-dimensional flow rates of the first and second unit of the system respectively, the seed cotton input into the first unit and the seed cotton output from the second unit should be approximately equal in order to obtain a suitable performance or satisfactory operation. For this reason, taking the non-dimensional flow rates to be equal (\( \bar{Q}_1 = \bar{Q}_2 \)), yields

\[ \bar{r} = \left( \frac{1 - \bar{b} \bar{r}}{\bar{b} \bar{r}} \right)^{1/3} \]

This equation gives the non-dimensional outer radius of the vanes in the first unit in terms of the non-dimensional inner radius of the second unit. From this equation, it can be seen that the outer radius of the first unit is dependent not only on the geometrical parameters of the second unit, but also on both the width of the first unit and the coefficient \( k₂ \). In this calculation, the seed cotton volume losses through the screen were neglected.

By considering the widths of the wiper bars and the carrying coefficients as/to be equal in two units correspondingly,
by writing \( \bar{b}_1 = \bar{b}_2 \) and \( k_1 = k_2 \), equation (6) can be re-written and may yield a second-order equation. The inner radius of the second unit can be extracted from this equation as follows:

\[
\bar{r}_{m2} = \frac{\pi \bar{z}_f}{2} \left( \frac{\pi^2 \bar{z}_f^2}{4} - \left( \bar{r}_{m1} - \bar{r}_{m2} \right)^2 \right)^{\frac{1}{2}}
\]

(7)

Since the first unit feeds the second unit, the two units should be considered together. There must be a dimensional relation, and the rotor velocities of these two units must be proportional. Otherwise, stuffing or blockage in the system may occur, and the desired efficiency cannot be obtained. Considering \( Q_1 \) is the flow rate of the first unit, and \( Q_2 \) that of the second unit, and neglecting the losses in the screen, the seed cotton flow rate from the first unit to the second unit must be determined. The relation between the angular velocities of these two units may be found by considering \( Q_1 \) and \( Q_2 \) are equal, so the non-dimensional flow rate and the angular velocity relation are obtained thus:

\[
\frac{\omega_1}{\omega_2} = \frac{Q_2}{Q_1}
\]

(8)

### Theoretical results and discussions

With the theoretical approach outlined above, the behaviour of the separator and the design parameters of its units concerned have been examined, and the results obtained are discussed below.

The variation of the non-dimensional cotton flow rate \( \bar{Q}_c \), with the non-dimensional outer radius of rotating vanes \( \bar{r}_{m2} \) for different vane width \( \bar{b}_1 \) is demonstrated in Figure 4. Although it may have different values in some applications, the factor \( k_1 \) was kept at 0.75, whereas the non-dimensional radius was varied from 0 to 1 and the non-dimensional width was changed from 0.1 to 0.5. It may be seen that increasing the radius generally decreases the flow rate in all width values, as expected. When a smaller vane width is introduced, the variation tends to be slightly different than in the case of the higher width. The variation is more marked at the highest vane width than the other width values. For low width, increasing the non-dimensional outer radius up to 0.5 (in others word with the reduced recess between the inner radius of the separator body and the outer radius of the vane), does not cause much difference in the cotton-carrying capacity. The flow rate or cotton-carrying capacity of the first separator unit seems to decrease more rapidly, with the radius ratio \( \bar{r}_{m2} \) being greater by approximately 0.5 for the width \( \bar{b}_1 \) values of 0.4 and over.

As expected, it seems to be the case that at \( \bar{r}_{m2} = 0 \) the maximum values of would be meaningless. No seed cotton carrying takes place at \( \bar{b}_1 = 1 \) due to the disappearance of volume in the unit. In industrial application, \( \bar{r}_{m2} \) takes the value between 0.8 and 0.9.

In a typical separator unit, \( r_{in} = 0.5 \) m for the non-dimensional outer radius \( r_{m2} \) of 0.8 and non-dimensional width \( \bar{b}_1 \) of 0.5, it may be seen from the figure corresponding to these parameters that the separator can carry a non-dimensional flow rate of \( \bar{Q}_c = 4.05 \), which in turn corresponds to a cotton flow of \( Q_c = 0.506 \) m³/s when the running speed is \( \omega = 1 \) r/s. It is found that the separator can carry 2769 tonnes of seed cotton per hour, considering the density of cotton as 1.52 gr/cm³. So from these group of curves, the performance of the separator can be predicted when the operating parameters and geometry are changed.

Since the cotton flow rate through the separator depends mainly on the geometrical and operating parameters of the second unit as explained above, the theoretical analysis was extended and the results given in Figure 5 has been produced for this purpose. The figure displays the non-dimensional flow rate obtained from the second unit \( \bar{Q}_c \) versus the inner radius \( \bar{r}_{m2} \) for different \( \bar{z}_f \) values at the fixed separator width of \( \bar{b}_1 = 1 \). The non-dimensional value of \( \bar{z}_f \) is varied from 0.1 to 0.5, and the non-dimensional radius \( \bar{r}_{m2} \) is varied from 0 to 1, while the carrying coefficient is kept constant at \( k_2 = 0.7 \). It is noted that an increase in \( \bar{z}_f \) (a decrease in the space full of cotton) causes a reduction in volume and hence the cotton flow rate. Increasing the inner radius of the unit up to a certain value increases \( \bar{Q}_c \), but an optimum non-dimensional radius exists which maximises the flow rate. Any further increase in \( \bar{r}_{m2} \) reduces the flow rate for all \( \bar{z}_f \) values down to zero. It may be observed that with a certain \( \bar{z}_f \) value (over 0.3) up to certain \( \bar{r}_{m2} \) values, the theory gives a negative flow rate, which means that the cotton delivery to the unit exhibits a backflow from the outlet, which is not logical. In these running conditions, when \( \bar{z}_f > 0.3 \), the zero points of the curves (giving a zero flow rate) shift to the higher \( \bar{r}_{m2} \) values.

These points, as well as the points coinciding with the peak of the curves, can be considered as design points. This is the most important conclusion arising from this theoretical study. Under these specific operating conditions, it appears that the negative flow is neither explicable nor desirable, and the question...
of the maximum points of the flow rate examination is found to be of primary importance. It may be observed that there are two different mode of operations in flow rate variation. These are marked as region I and region II in the figure. It is seen that for a limiting value of \( r_{in} \), the flow rate approaches very high values for all values of \( z_f \). In the first mode (region I) increasing radius increases the flow rate contrary to the very low \( z_f \) curves. For the successful performance of separation, the boundary value of radius defining the two district region (I, II) should be determined. In this analysis, the limiting value of the radius is 0.2 for \( z_f = 0.1 \), taking the value of \( Q_{in} = 14.88 \), whereas this limit takes the value of 0.8 for \( z_f = 0.5 \), having the value of \( =0.966 \). From this figure it may be concluded that region II is recommended to designers as the design region.

The relationship between the non-dimensional flow rate ratio and the dimensional radius ratio of the separator as a whole for different running speed ratios may be seen in Figure 6. This figure examines the interrelation between the magnitude of flow rates to be obtained from both successive units of the separator and the corresponding radius and angular velocity ratios. The radius ratio \( r_{in}/r_{in} \) is varied from 0 to 5, while the angular velocity ratio of the two units of separator \( \omega_1/\omega_2 \) is changed from 0.3 to 0.7. Due to the design principle and the construction of the separator, the speed of the second unit should be greater than that of the first. It may be seen that the value of \( Q_{in}/Q_{in} \) is proportional to the cubic power of the radius ratio \( r_{in}/r_{in} \) and the increasing radius ratio increases the flow rate ratio for all speed range. In common industrial applications, \( r_{in} \) is set between 0.5 and 1m, and \( r_{in} \) is set between 0.2 and 0.4 m. It can be estimated that the radius ratio may be in an interval of 2 to 3. Because of the constructional restriction of the separator, the ratio of the angular velocities of two units can be taken at around 0.5. In this theoretical study, the suggested parameters \( r_{in}/r_{in} = 2.5 \) and \( \omega_1/\omega_2 = 0.5 \) produce \( Q_{in}/Q_{in} \) as 7.8125.

The variation of angular velocity ratio of the separator with the geometry of the two intermediate units may be illustrated as in Figure 7. Here, the dimensional radius ratio is varied from 0 to 1 while the non-dimensional inner radius of the second unit is changed from 0.2 to 0.4. In this variation, the specific parameters are taken as shown in the figure. It may be seen that with all \( r_{in} \) values, the speed ratio remains nearly constant up to a radius ratio value of approximately 0.3. Any further increase in the radius ratio results in a rapid increase in the speed ratio. The variations of speed with different inner radius values of the second unit \( (r_{in}) \) seem to be very close to each other, and it should be noted that for these geometrical parameters, the suggested design points fall within the interval of \( r_{in}/r_{in} =0.4 \) to 0.6 and the corresponding angular velocity ratio of 0.16 to 0.53. Again the first unit should be run at a slower speed than the second unit.

In order to estimate the non-dimensional flow rate produced from the second unit with a given non-dimensional flow rate originated from the first unit of the separator, a number of arithmetical processes and some assumptions have been performed. With the assumptions made as \( k_1 = k_2 = 0.7 \), \( b_1 = b_2 = 1 \) and for \( z_f = 0.2 \),
and \( z_f = 0.3 \), and expressing the equation giving \( Q_1 \) in terms of \( r_{out} \), and in turn with regard to \( Q_1 \), the variation illustrated in Figure 8 has been obtained. As expected for a given \( Q_1 \) value, increasing \( z_f \) increases the non-dimensional flow rate \( Q_1 \) and increasing \( z_f \) decreases \( Q_1 \) for both \( z_f \) values. For certain \( Q_1 \) values, the \( Q_1 \) values decrease down to zero, and any further increase produces negative flow rate, which is not tolerable. From these figures, the intention is to select the maximum \( Q_1 \) values with respect to \( Q_1 \). In this theoretical approach, the acceptable interval for \( Q_1 \) falls within \( Q_1 \), whereas \( Q_1 \) takes the value 0.8. From the optimum flow rate obtained from the second unit, it may be concluded that there is a region on which can be recommended to the designer as the design region.

3. The theory also predicts that there will be an upper limit to the inner radius of the second unit for which a successful operation can be guaranteed. Depending on the \( z_f \) values, the limiting value of radius \( r_{in} \) is 0.2 for \( z_f = 0.1 \), whereas for \( z_f = 0.5 \) the radius takes the value 0.8. From the optimum flow rate obtained from the second unit, it may be concluded that there is a region on which can be recommended to the designer as the design region.

4. Since the first unit of a separator feeds the second unit, the two units should be considered together, and it was shown that there must be a dimensional relation between them and the rotor velocities must be proportional to each other. From this theoretical approach, due to the constructional restriction, the ratio of angular velocities can be taken around 0.5 and the suggested geometrical parameters should fall within the range \( r_{in} = 0.4 \) to 0.6. The first unit should be run at a slower speed than the second unit.

5. From this analysis, it is possible to estimate the non-dimensional flow rate produced from the second unit with a given non-dimensional flow rate obtained from the first unit of the separator; the predicted geometrical sizes of the units would take the values as \( r_{in} = 0.85 \) and \( r_{out} = 0.4 \) for a successful operation. The examination would also define an upper limit region for both \( r_{in} \) and \( r_{out} \) for different \( z_f \) values; these points are suggested to the designers as design points.

6. Using the non-dimensional parameters defined, it is always easy and useful to calculate the dimensional parameters such as flow and radius, by taking into account the different geometrical and operating parameters.

7. The remarks outlined in this paper and the results concerning the dynamic behaviour of the units which is under investigation (which will be presented as Part II of this research) would be considered as a design tool for designers of saw-gin ginning machinery with special reference to separator design. However, further experimental substantiation of the results predicted from the model ought to be carried out.

References


Received 09.07.2004 Reviewed 16.05.2005