

Fibre Dynamics in the Revolving-Flats Card Part I

A Critical Review

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Abstract

The last several decades have seen significant developments to the revolving-flats card and much research has been published on the fundamentals of the carding process. There are still, however, contradictions in the detailed explanation of fibre behaviour during carding and in the effectiveness of certain developments widely accepted as beneficial. This paper presents a critical review of the literature concerning the way fibre mass is disentangled into individual fibres to form a card sliver and the effectiveness of principal machine components. Areas are indicated where further research is necessary to resolve contradictory views and further the understanding of the process.

Introduction

Over the last 30 years numerous developments have taken place with the cotton card. The production rate has risen by a factor of 5 [1] with the main rotating components running at significantly higher speeds. Triple taker-in rollers and modified feed systems are in use, additional carding segments are fitted for more effective fibre opening, and improved wire clothing profiles have been developed for a better carding action. Advances in electronics have provided much improved monitoring and process control. Most of these developments have resulted in enhanced cleaning of cotton fibres, reduced neppiness of the card web and better sliver uniformity.

Despite the various improvements made to the card a commonly held view is that more is known about the cleaning processes on the card than about the carding process itself [1]. For instance, modern cards can achieve an overall cleaning efficiency of 95%. It is well established that the cleaning efficiency of modern taker-in systems is a round 30%, that the cylinder/flats action with the latest wire clothing profiles gives 90% cleaning efficiency and that effective cleaning is associated with lower neps in the card web [1][2][3]. However, even though the nep content and the sliver Uster CV% are used as quality measures of carding performance they are not satisfactory indicators for anticipating yarn quality. This is because some fibre arrangements in the sliver may lead to nep formation and imperfections during up-stream drafting processes [4]. In addition to the removal of trash and neps, important aspects of the carding process in relation to yarn quality and spinning performance are the degree of fibre individualisation, the fibre extent and the fibre hook configurations in the sliver. With regard to these factors, increased production rate can reduce carding quality [5][6][7][8]. It is therefore of importance that a better understanding is established of the effect that carding actions have on such quality parameters, particularly at high production rates.

The most widely accepted view of how fibres are distributed within the card under steady-state conditions is illustrated in Figure 1 [9]. Reported studies into the fundamentals of the carding process have largely been concerned with how the principal working components of the card affect this distribution of fibre mass and interact with the mass to achieve: trash and nep removal from cottons; the disentangling of the fibre mass into individual fibres, with minimal fibre breakage; and the alignment of the fibres to give a sliver suitable for drafting in down stream processes. These actions occur at the interface of the card components within the three zones indicated in Figure 1. This paper therefore gives a critical review of published research on the:

- mechanisms by which the fibre mass is broken down into individual fibres,
- mechanisms of fibre transfer between the component parts of the card
- effect of the saw-tooth wire geometry on these actions

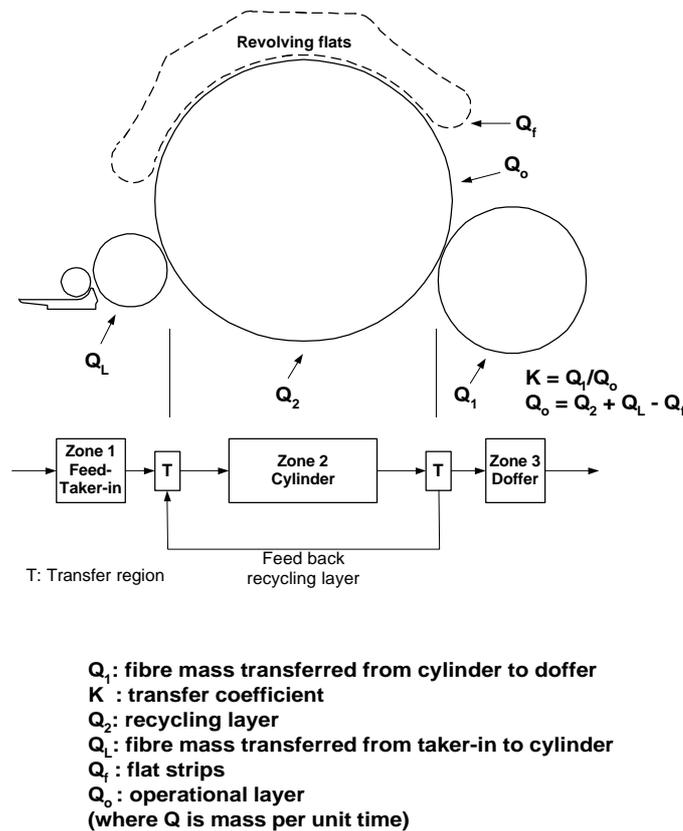


Figure 1: Distribution of Fibre Mass during Short-Staple Carding

Zone 1: Fibre-Opening

Separation and Cleaning of the Input Fibre Mass:

The taker-in has effectively a combing action [10], which results in the breakdown of the tufts, constituting the fed fibre mass, into single fibres and smaller size tufts (tufflets), and in the liberation of trash particles ejected from the mass flow by the mote knives positioned below the taker-in. To effectively breakdown the fibre mass feed into tufflets with minimal fibre breakage, the taker-in wire has to be coarse, with a low number of points per unit area (4.2 to 6.2 pcm²) and not too acute an angle of rake [10][11]. The objective is to obtain gentle opening of the fibre mass feed and easy transfer of the tufflets to the cylinder. Angles of 80° – 85° are used for short and medium length cottons to give effective opening and cleaning. For longer cottons and synthetics, a 90° or negative rake may be needed to facilitate gentler opening and satisfactory fibre transfer to prevent lapping of the taker-in [11].

Fibres, usually very short fibres, which are not adequately held by the teeth or present in the interspaces of the clothing are ejected causing fibre loss. However, it is the mote knives that govern the amount of fibre to trash (i.e. lint) in the extracted waste. Experimenting with the settings of two mote knives below the taker-in, Hodgson [12] found that the absence of the knives greatly increased the lint content with little increase in trash. With the knives present, the best setting was that which gave the least waste since increasing the amount of waste did not improve cleaning. Artzt [2] found that irrespective of teeth density and tooth angle the waste increased with taker-in speed but the increase was attributed to higher lint content.

It is reasonable to assume that the smaller the tufflet size and the greater the mass ratio of individual fibres to tufflets the better the cleaning effect of the taker-in. Supanekar and Nerurkar [13] suggest that the taker-in breaks down the fibre feed into tufflets of various sizes and mass, conforming to a normal frequency distribution. See Figure 2. In the case of cotton, some tufflets may consist of only fibres whilst others will contain seed or trash particles embedded among the fibres, these tufflets constituting the heavier end of the distribution curve. Thus, the mean of the distribution would depend on the trash content of the material, as well as on the production rate, the taker-in speed and the wire clothing specification. However, the authors did not report any data to support their ideas. Little detailed information has yet been published on the mass

variation of tuftlets or on the relative proportion of discrete fibres to tuftlets resulting from the combing action of the taker-in. Nittsu et al [14] using photographic techniques studied the effect of process variables on tuftlet size. It was found that the total number of tuftlets decreases the closer the feed plate setting, the lower the feed rate, the smaller the steeper rake of the saw-tooth clothing and the higher the licker-in speed. Since the licker-in opens the batt into both tuftlets and individual fibres, a decrease in the total number of tuftlets suggests an increase in the mass of individual fibres. Liefeld [15] calculated estimates of the opened fibre mass at various stages through the blowroom and gives a value of 50µg for tuftlets on the taker-in. Mills [16] claims that the calculated optimum number of fibre per tooth is one, and that this should be maintained at increased production rates by increasing the taker-in speed. There is, however, the question of fibre damage at high taker-in speeds.

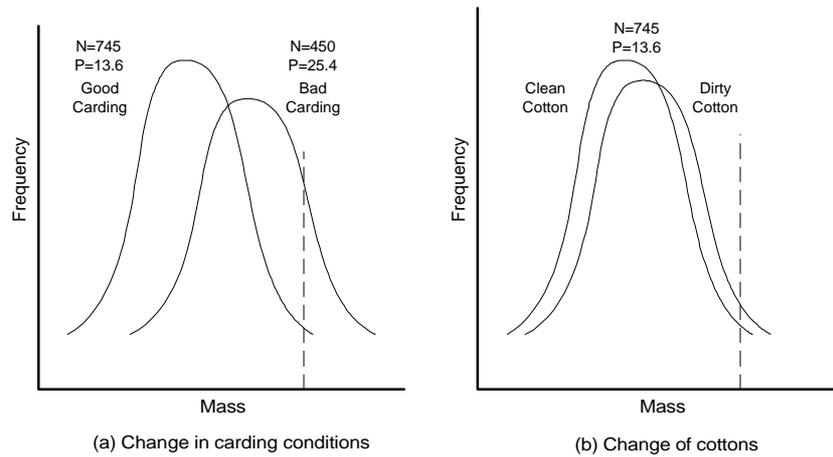


Figure 2: Frequency distribution of tuftlet mass
 N: Taker-in speed (rpm), P: Production rate (kg/hr)

Honold and Brown [17] found no fibre damage occurred at speeds of up to 600 r/min. Krylov [9] reports the absence of fibre breakage at speeds up to 1,380 r/min, and Artzt's [2] work shows taker-in speeds to have a negligible effect on fibre shortening and subsequently on yarn strength. In all cases cotton fibres of 26.5-30.2 mm (2.5% span length) and 3.8 – 4.9 micronaire were processed. The level of fibre breakage, however, would seem to depend on production rate and the batt fringe setting to the licker-in []. High production rates achieved by increased sliver counts and a close setting of the batt fringe result in significant fibre breakage. No fundamental studies have been reported on the forces involved in the fibre-wire interaction of revolving-flat card components. However, Li and et al [18] report a simulated study of fibre-withdrawal forces for wool in high-speed roller- clearer cards. Although impact forces could cause damage [19][20], it was found that card component speeds had no significant effect on the withdrawal-force, and that fibre configuration and entanglement were the important factors.

The importance of producing small size tuftlets is evident from the various components fitted in the fibre-opening zone on modern short-staple cards. Saw-tooth wire covered plates, termed combing segments, fitted below the taker-in or built into the taker-in screen are claimed to give improved trash removal. Reportedly [21][22], the stationary flats fitted between the taker-in and the revolving flats provide extra opening of the tuftlets transferred to the cylinder from the taker-in. They also act as a barrier to large, hard, trash particles such as seed coats, protecting the wire of the revolving flats from damage, particularly at high cylinder speeds. This enables finer wire to be used for the revolving flats and thereby improves the cleaning effect of the interaction between cylinder and revolving flats. The chances are also reduced of longer length fibres becoming deeply embedded in the revolving flats to become part of the flat strips. These attachments are widely accepted by the industry as beneficial, particularly at high production speed. However, there is no published systematic study of their effectiveness in reducing tuft size, and the effect of stationary flats on the recycling layer, Q_2 , is unknown. The little information that is available attempts to illustrate the effectiveness of these components on yarn quality, but there is no evidence of analytical rigour in the way the data were obtained.

Fig 3 shows the effect of the combing segment and the stationary flats on dust deposits in rotor spinning and on the imperfections in several types of ring spun yarn. The figure includes values for the effect of stationary flats above the doffer, but this will be considered in a later section. It would appear that the added

components in the taker-in region might well reduce the dust deposit in the rotor, but the results showing improvements in yarn quality are not convincing, and in all cases the stationary flats above the doffer appear the most effective.

Leifeld [1] reports that the cylinder – revolving flats carding action occurs when the fibre mass delivered to the cylinder is in a highly opened state. Tandem cards are said to give a high standard of carding with low nep and trash levels in the card web [23][24]. This is because a uniform web of almost discrete fibres is fed to the second cylinder of the tandem card and closer revolving flat settings with higher cylinder speeds can be used [1][24]. Single taker-in systems, even with combing segments and stationary flats, cannot give as high a degree of opening. However, Leifeld reports that a triple taker-in system facilitates high taker-in speeds and, fitted to a single-cylinder card, feeds a uniform web of discrete fibres to the cylinder, thereby offering a more cost-effective process than the tandem card, but no comparative data for the two types of card are given. Although it may be reasoned that a triple taker-in action should improve nep removal, it is of importance to compare the web qualities with regard to dust and trash content, the level and type of fibre hooks, and the degree of fibre parallelism since these greatly influence yarn quality.

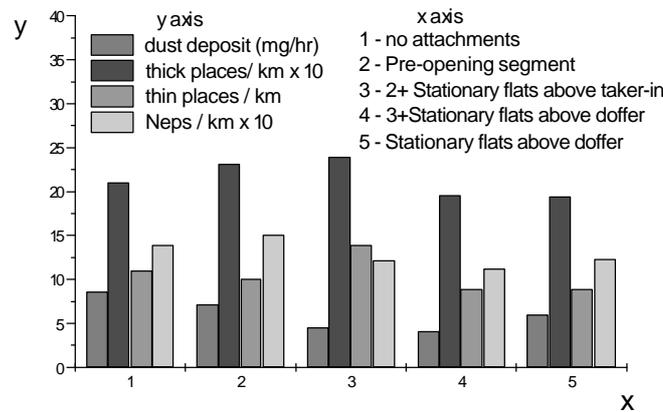


Figure 3: Effect of Combing Segment and Stationary Flats

Contradicting the triple taker-in approach, Mills [16] states that the fibrous material fed to the card should not be broken down into individual fibres by the taker-in system. This is because the fibres would remain largely disoriented with a high proportion of them lying transversely to the direction of mass flow when transferred to the cylinder and subsequently to the revolving flats. This can result in fibre loss during transfer to the cylinder and an unevenness of the fibre mass across the cylinder width, causing neps to be formed and degrading the carding action between the cylinder and the revolving flats. It is claimed that good carding requires a thin, uniformly distributed sheet of well-opened tuftlets fed to the cylinder from the taker-in. Fujino [25] reports results that would appear to confirm the view that as the level of opening increases through faster taker-in speed, the degree of fibre parallelism on transfer to the cylinder decreases. The nep level in the card web was, however, observed to decrease noticeably with increased taker-in speed. This was attributed to the reduced speed ratio of the cylinder and taker-in. Artzt[2] found that reducing the taker-in/cylinder draft ratio from 2.4 to 1.4 caused yarn imperfections to increase. In contrast to these findings Harrison [23] states that increasing taker-in speed did not affect the nep level in the card web, the exception being for low micronaire cottons. The apparent contradictions in these results suggest that a better understanding of the transfer mechanism may be needed which takes into account fibre properties.

Fibre Mass Transfer to Cylinder

Two contrasting views have been reported on the mechanism of fibre transfer. Oxley [26] suggests that the fibre mass on the taker-in is ejected between the cylinder wire and the back plate. Whereas Varga[10] believes that the fibre mass is stripped from the taker-in in the following way. In the feed to the card, tufts and fibres lie randomly and by the action of the taker-in are brought into length-wise orientation in the direction of the roller rotation. The trailing ends of newly formed tuftlets protrude above the taker-in wire and are easily stripped by the cylinder wire clothing. This implies that the transfer involves a reversal of the

leading and trailing ends of the fibres. Further orientation and parallelism of the fibre mass is thought to occur during the transfer onto the cylinder.

No experimental work has been published which specifically involves a study of the transfer of fibres from the taker-in to the cylinder. Therefore it has yet to be established whether at the interface, the cylinder, which has the faster surface speed, strips the fibre mass with its clothing or the taker-in, through the action of centrifugal forces, ejects the tuftlets and single fibres onto the cylinder, or a combination of both occurs. It is also of interest to determine if the airflow in the region assists the fibre mass transfer. Whatever the case, the fibre mass is likely to be subjected to an uncontrolled drafting effect, which could introduce irregularities in the mass flow.

Zone 2: The Fibre Carding Zone

In the carding zone, it is the interaction of the fibre mass and the wire-teeth clothing of cylinder and flats that fully individualises the fibres and gives parallelism to the fibre mass flow.

In considering how fibres enter and are individualised in the carding zone, Oxley [26] suggests that tuftlets are not strongly held on the cylinder clothing because the tooth angle faces the direction of cylinder rotation. They are, thus, easily removed and more firmly held by the opposing teeth of the flats. It is therefore assumed that as a flat enters the carding zone it becomes almost fully loaded with fibres, the airflow within the region assisting the fibre mass transfer. Having been stripped of fibre mass, subsequent following areas of the cylinder wire clothing move past the fully loaded flat and proceed to comb fibres from the flat, carrying them towards the doffer. The action of combing causes the fibres to be hooked around the cylinder wire points and prevents them from being easily removed by other flats. Debar and Watson's [27] experiments of the movement of radioactive tracer fibres through a miniature card showed that some fibres caught by the flats were often only removed by the cylinder-wire clothing after many revolutions of the cylinder.

Varga [10] reports an alternative view to Oxley's, stating that two types of action occur at the cylinder-flats interface. First, a carding action where the upper layer of a tuftlet or a loosely opened fibre group is caught and held by the flats whilst simultaneously the bottom layer is sheared away by the fast moving cylinder surface. This action causes the top to hang from the flats and to contact subsequent parts of the cylinder wire surface resulting in the second action which is combing, where the wire clothing of the cylinder hooks single or a small group of fibres and combs them from the top layer. A second flat catches the bottom layer on the cylinder and the actions are repeated. In this way tuftlets or groups of fibres are separated into individual fibres.

By making abrupt changes in the colour of the fibre mass fed to the card, Oxley[26] demonstrated that tuftlets from the load on a given flat are carried forward by the cylinder clothing and separated into individual fibres over a small number of preceding flats, typically 4. It was concluded that the interchange of fibres between cylinder and flats does not occur over the full carding zone. Sengupta and et al [28] made measurements of the carding/combing forces and showed that essentially these actions were on average confined to the first ten working flats.

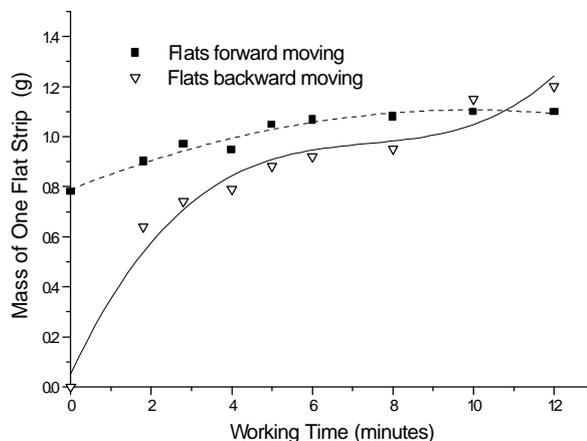


Figure 4: Relation of Flat Load and Working Time

A study by Hodgson [12] showed that moving in the direction of the cylinder rotation, a given flat acquires two-thirds of its final load directly it comes into position over the cylinder. The load then increases exponentially with time, reaching nine-tenths of the final value within 6-8 minutes. Completion of the load takes place slowly during the remainder of the working time. See Fig 4. As shown in the figure, with flats moving in the reverse direction the load first increases rapidly with time and then slows until the flat is about to leave the working area. Here it encounters the fibre layer being transported on the cylinder surface from the taker-in. The flat receives a sudden addition of fibre mass to become fully loaded, and, in agreement with other results [29], the load weighs more than for the forward direction of motion. Contrary to Oxley's conclusions, it was found that 30% of the final load on a given flat resulted from fibre interchange between flats and cylinder over the full carding zone.

It may be reasoned that the number of flats involved in separating a tuftlet depends on the tuftlet size, the mass flow rate and the flat setting. Large tuftlets will be pressed into the cylinder wire during the carding action, whereas small tuftlets will be more easily carded and will remain at the top of the cylinder wire teeth [29]. The larger the tuftlet, the higher the production rate and the closer the flat settings, the greater the number flats involved in the separation of a given tuftlet.

Bogdan[29] reports that flats tend to load quickly at the beginning of their cycle of contact with the cylinder. This, however, is only a partial loading, since the fibre mass tends to resist more fibres entering the space but, in the case of cotton, not the leaf and trash particles present.

Analysis of the trash in cotton flat strips showed that initially the percentage of trash in a given flat strip is low and increases slowly during the first 10 minutes of carding, then remains at almost a constant value [12]. The final percentage depends on the trash content of the cotton. For a fixed production rate, the amount of flat strips was found to be directly proportional to the flat speed, but provided the speed was such that the working time was not less than 10 minutes, both the weight and composition of the flat strips remained approximately constant. Feil[30] claims that a high degree of air turbulence exists in the flat/cylinder zone. A combination of centrifugal forces, mechanical contact with the flat wire and air turbulence causes the trailing ends of fibres attached individually to the cylinder clothing to vibrate and shake loose trash and dust particles. Short fibres which cannot adequately cling to the cylinder clothing will also be shaken free, and along with impurities become part of the flat strips.

Fibres that are deeply embedded in the flats, and cannot be reached by the cylinder wires become flat strips. For this reason the closeness of the flats setting to the cylinder is important. It may be assumed that closer flats/cylinder setting and faster cylinder speeds will give more effective carding and combing actions as described by Varga and thereby improve web quality through reduced neps [23] and trash [28]. Cylinder diameters vary and Karasev [31] showed mathematically that for a given cylinder rotational speed the carding power will be greater for a larger cylinder diameter with a higher number of working flats. However, because of lower mechanical stresses, smaller cylinders can be rotated at higher speeds than larger cylinders. The above advantage is therefore reduced the higher the speed of the smaller cylinder.

Artzt and et al[2] studying the influence of card clothing parameters and cylinder speeds on yarn imperfections, report that the teeth density of the flats and cylinder, and the speed of the cylinder must prevent tuftlets lying within the spiral pitch of the cylinder clothing. If this occurs the tuftlets generally become the thick places in the yarn. It was found that high teeth densities and low cylinder speeds were as effective as lower teeth densities and high cylinder speed. High teeth densities with high cylinder speeds did not give effective carding, but no reason was reported for this.

Since the action of the cylinder in this region is to individualise fibres, the wire clothing on the cylinder has a steeper rake and a higher point density than the wire clothing of the flats. Thus, with closer settings and higher cylinder speeds greater forces may be involved and may result in fibre breakage. However, the work of Li and et al [18] indicates that the withdrawal forces needed to separate an entangled fibre mass was largely dependent on the density of the fibre mass and the contact angle fibres made with the wire clothing, than on the machine speeds.

Van Alphen [32] reports that increasing cylinder speed causes more fibre breakage than increasing taker-in speed and that this is reflected in the yarn properties. Rotor yarn tenacity was reduced by up to 5% with increasing cylinder speeds between 480 –600 r/min. Whereas ring yarns showed a 5% reduction for speeds between 260 – 380 r/min and 10% at 600 r/min. The higher sensitivity of ring yarns to fibre breakage was attributed to the negative effect of short fibres during roller drafting. Krylov [9] reports that no fibre shortening was observed for cylinder speeds up to 380 r/min.

It may be reasoned that the smaller the tuftlets and the more parallel fibres in tuftlets are to the direction of mass flow the lower the probability of fibre breakage. Honold [17] attributes fibre damage to the cylinder/flat interaction and suggested that the degree of damage depends on the size of the tuftlets entering the working area; the smaller the tuftlets, the closer the setting that can be used and the lower the fibre breakage [55]. Hodgson's [12] work showed fibre length is also an important factor. For cottons, fibre breakage was only found to have occurred when the staple length was greater than 25mm. Increasing the flat speed appears to have no effect on fibre breakage. However, the amount of flat strips increased proportionally with the flat speed [12] and the mean fibre length of the strips increased significantly. This means that faster flat speeds result in larger amounts of useable fibre in the waste. Interestingly, when carding cottons, immature fibres were not readily found in the flat strips. The coarser rigid fibres seem more easily retained by the flats.

The effectiveness of the carding and combing actions within the cylinder/flats area is, inter alia, dependent on the quantity of fibre mass on the cylinder, and this includes the recycling layer, Q_2 . It is of interest therefore to consider how the Q_2 is formed during fibre transfer from cylinder to doffer, and its importance to the card web quality.

Zone 3: Cylinder / Doffer Interaction

Varga [10] reports that the action of fibre mass transfer to the doffer is similar to the transfer at the input to the cylinder-flats zone. The regions above and below the line of closest approach of the cylinder to the doffer (i.e. the setting line) are important to the mechanism of fibre mass transfer and the transfer coefficient, K. The two regions may be termed the top and bottom co-operation arcs or top and bottom zones. Simpson [33] claims that transfer can occur in both zones and that the particular region in which transfer actually occurs influences the fibre configuration and the nep level of the card web, although cylinder-flats action is more important in reducing neps. Which zone transfer occurs in is dependent on the cylinder-doffer surface speed ratio, C/D. For high C/Ds, transfer occurs in the top zone and results in a larger number of trailing than leading hook fibres and a low nep level. The reverse occurs when transfer takes place in the bottom zone owing to lower C/Ds. Simpson does not however say at what C/D value transfer changes from one zone to the other. Although reference is made to other authors who have proposed a mechanism for fibre transfer in the top zone, no mechanism or experimental evidence is given to support the idea of fibre transfer in the bottom zone. Lauber and Wulfhorst [34] used laser-doppler anemometry and high-speed cine photography to study fibre behaviour in the bottom zone, i.e. up to 110 mm below the setting line. Their findings showed no evidence of fibre transfer within the bottom zone.

Since Morton and Summers' work in 1949 [35] other researchers have confirmed that the values given in Table 1 for the five classes of fibre configuration observed in slivers. It is of interest to note that the hooked lengths are greater for leading than trailing hooks. Although, the calendar draft can be used to change the relative proportions, Gosh and Bhaduri [36] showed that the method of removing the web from the doffer does not influence the propensity of any class of configuration. It is the mechanism of transfer that is seen as principally responsible for the shape fibres have in the sliver.

Table 1: Classification of Fibre Configuration in Card Sliver

Calendar Draft	Group I Leading Hooks		Group II Trailing Hooks		Group III Both ends Hooked		Group IV No Hooks		Group V Other	
	%	M.F.E (mm)	%	M.F.E (mm)	%	M.F.E (mm)	%	M.F.E (mm)	%	M.F.E (mm)
	19	17.3	51.0	17.1	13	18.6	16	18.9	1	10.0
1.07	18	18.7	50.0	17.4	12	16.0	16	21.4	4	7.0
1.11	12	20.0	52.0	15.8	15	13.0	19	22.3	2	8.5
1.25	16	20.0	38.0	18.9	13	14.3	32	23.5	1	12.0
Mean	16.25	19.0	47.75	17.3	13.25	15.7	20.75	21.5	2	9.37

Source: Ref. [37] M.F.E – mean fibre extent

Several studies have been reported on the fibre-mass-transfer mechanism [37][36][38][39][35][40][6][41][42]. A number used tracer fibres with one end of a fibre dyed a different colour from the other. The reported findings [41] suggest that fibre mass transfer occurs by fibres acting independently and not as

a web of fibres. Observations showed that prior to transfer, nearly 70% of fibres on the cylinder had leading hooks, only 9% had trailing hooks. On transfer the relative proportions changed as indicated in Table 2. Half the number observed underwent reversals, with greater than 70% changing their configurations [e.g. leading hooks becoming trailing hooks]. Of those that transferred without reversals ca 90% did so with a change of configuration.

Table 2: Mode of Fibre Transfer from Cylinder to Doffer

Configuration	On Cylinder (%)	Mode of fibre transfer to doffer			
		Reversal (%)		No reversal (%)	
		No change of config.	Change of config.	No change of config.	Change of config.
Trailing	4.5	2.25	2.25	0.00	0.00
Leading	63.7	15.90	13.70	4.50	29.60
No hooks	27.3	2.20	11.45	2.20	11.45
Both ends hook	4.5	0.00	2.25	0.00	2.25
Total	100.0	20.35	29.65	6.7	43.30

Ghosh and Bhaduri [36] report that tracer fibres were noted generally to go around with the cylinder for several revolutions before being transferred by the doffer. On occasions transfer only happened when the cylinder speed was increased. Debar and Watson's [27] work with radioactive viscose tracer fibres showed that a fibre on the cylinder wire passes the doffer up to a maximum 20 times before being removed by the doffer, sometimes interchanging several times between the cylinder and flats, during the 20 revolutions on the cylinder. Hodgson [12] found that cotton fibres make between 10 and 25 cylinder revolutions before being removed by the doffer. With the continuity of fibre mass flow through the card, this means that the doffer web is built up over many cylinder revolutions and that the recycling layer, Q_2 , is comprised of multiple fractional layers of the fibre mass transferred from taker-in to cylinder during these cylinder revolutions [12].

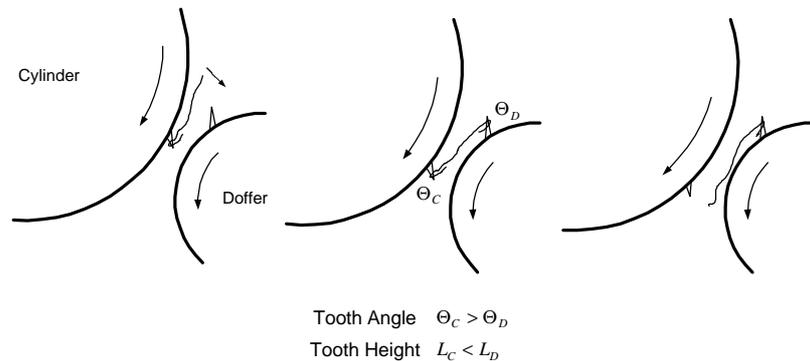


Figure 5: Mechanism of fibre transfer for trailing hook formation

A proposed hypothesis [36][35] for the mechanism of fibre transfer is illustrated in Figure 5. Here the trailing ends of fibres are lifted from the cylinder surface by centrifugal forces and become hooked around the teeth of the doffer clothing. The frictional drag of the doffer clothing eventually removes these fibre from the cylinder clothing. This mechanism only explains the formation, without reversal, of trailing hooks in the doffer web. However, the importance to fibre transfer of the relative angles and tooth lengths of the cylinder and doffer is self evident from the figure.

Baturin [37] developed equations that showed the importance of tooth angle and teeth density of the cylinder and doffer wires to the value of K and thereby Q_2 . Other investigators [43][7] have reported experimental data that verify Baturin's equations. It was found that the more acute the working angle of the doffer wire compared to the cylinder wire, the higher the value of K , and the lower Q_2 , and that higher teeth densities on the doffer increased K . These findings would tend to suggest that the proposed mechanism is a principal action by which fibres are removed from the cylinder. However, this mechanism of fibre transfer does not explain the change of fibre configuration with reversals and the formation of leading hooks in the doffer web. It also does not explain how fibres forming the recycling layer, Q_2 , are subsequently removed, even though an input layer of fibre mass is added to Q_2 each time it passes the taker-in.

The above studies did not take account of the degree of fibre parallelism on the cylinder prior to transfer, nor the number of fibres per tooth on the cylinder and consequently the likelihood of fibre interaction during transfer. Fujino and Itani [25] used a microscopic technique to observe the orientation of fibres on the cylinder surface above the taker-in and just before the doffer, and in the doffer web. They found that fibres showed the highest degree of parallelism when on the cylinder surface just above the doffer. The degree of parallelism decreases on transfer to the doffer, and further deteriorates when the web is removed from the doffer to form the sliver, even though the calendar draft helps to maintain some degree of parallelism.

Grimshaw [22] and others[21][44] report the use of fixed flats just before the cylinder/doffer top transfer zone, to improve fibre parallelism in the card web.; up to 20% reduction in fibre hooks and 25% improvement in fibre parallelism were obtained in the card web, resulting in improved yarn properties. Figure 3 shows that the fixed flats in this region are more effective in improving yarn properties compared with the fixed flats above the taker-in. The action of the flats fitted above the doffer is not fully understood. It is assumed that they tend to lift the fibres to the tip of the cylinder wire for more effective transfer to the doffer, particularly at high cylinder speed. Lauber and Wolfhorst [34], Kamogawa, et al [45] report that in this region aerodynamic forces affect the parallelism of the fibres and the way they are transferred to the doffer. However, no details are given.

Owing to the higher speed and larger diameter of the cylinder, it is assumed that during transfer in the top zone the fibres are more substantially affected by the flow of air transported with the cylinder's than by the doffer's wire clothing. High-speed photographs [34] showed that in the bottom zone the main flow of fibre mass was with the doffer at close to the doffer speed, even when the fibres were just below the cylinder-doffer setting line. However, some fibres were seen to be free of both the doffer and cylinder and tended to move with the air currents and eventually with the motion of the cylinder surface.

From the above discussion, it can be seen that work is still needed to establish a more detailed understanding of fibre mass transfer between the cylinder and doffer. The results of such work may also help in better explaining how fibres remain on the cylinder to form the recycling layer Q_2 . Varga [10] suggests that with fibre transfer in the top zone, the thicker layer of web on the doffer surface protrudes above the doffer wire and into the gap setting between doffer and cylinder. The faster moving cylinder wire clothing combs through the doffer web and thereby pulls fibres back onto the cylinder surface. De Swann [46] showed that fibres can be readily transferred from the doffer to the cylinder as well as from cylinder to doffer. In Hodgson's study [12], changing cylinder/doffer setting affected the neppiness of the web but did not affect K , which seems to contradict Varga's view. Baturin [47] and Simpson [6] however showed that K will increase if the region of interaction between the cylinder and doffer is reduce by decreasing the doffer or the cylinder diameter and this tend to supports Varga's suggestion for a combing and robbing action of the cylinder. It is reasonable to assume that the combing action could lead to fibres in Class II and IV (Table 1), but there is still no verified explanation of how fibres in Classes I, III, and V are formed, with and without reversals.

Much of the research on the cylinder / doffer interaction concerns the effect of machine variables on the size of Q_2 (or the operational layer, Q_o), on the web quality and changes to the relative proportions of the classified configurations, and on ultimately the yarn quality.

Sing and Swani [48] developed a Markovian model for the carding process in order to determine the probabilities of fibre transfer between cylinder and flats and cylinder and doffer, taking into account the recycling of fibres. It was shown that the times spent by a fibre on the cylinder, T_r , and in the flats/cylinder region, T_d , are given by:

$$T_r = 1 / K \text{ and } T_d = T_r \cdot P_f \dots\dots\dots (1)$$

Where $K = Q_1 / Q_o$ and $P_f = Q_f / Q_o$

Reported values for K would seem to vary between 0.2% to 20% [9], depending on doffer and cylinder speeds, on the relative profiles of the saw-tooth wire clothing, and on the sliver count. Simpson [7] suggests that fibre properties are also of importance, in that there is a tendency for low micronaire cottons to give higher cylinder loading and for fibres with low shear friction and good compression recovery to result in higher K values. No physical explanation is given for these findings and no other studies are reported on the effect of fibre properties. Further work is therefore needed in this area.

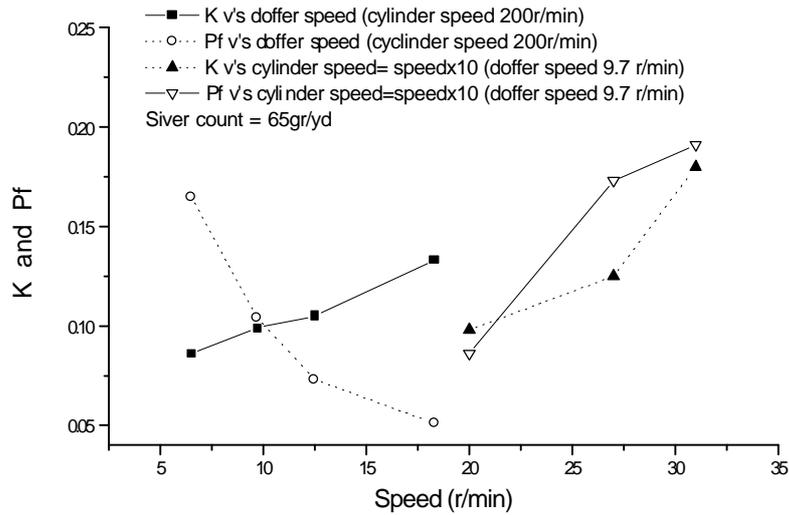


Figure 6: Effect of Cylinder and Doffer Speed on K and P_f

A popular view is that a low fibre mass entering the cylinder/flats interface, i.e. a low fibre load on the cylinder, results in better quality carding [1]. This would seem to imply that the higher the value of K the better the carding since less fibre mass is recycling to be added to the mass transferred from the taker-in. However, there are several ways of increasing K and not all of them result in improved carding quality. Figure 6, shows that for a given cylinder speed and sliver count, increased doffer speed increases K and reduces P_f , whereas keeping the doffer speed and sliver count constant and increasing the cylinder speed increase both K and P_f . For constant cylinder and doffer speeds, increased sliver count was found to reduce K and P_f .

If the same up stream machinery is used, then the best measure of effective carding is the quality of the carded ring-spun yarns produced [49]. Gosh and Bhaduri's[38] work showed that for a fixed carding rate, with increasing doffer or cylinder speed, K increases but Q_o and the yarn imperfections decrease; no trend was found with yarn tenacity or irregularity. Singh and Swani studied the properties of yarns made from slivers corresponding to differing K and P_f values and found that P_f was the more important of the two parameters, in that the higher the value of P_f the better the yarn quality. Kaufman [50] reports that the lighter the fibre load is on the flats, the better the carding quality. Thus, the use of P_f does not give an adequate understanding of the importance of the recycling layer nor of the size of the fibre mass load at the cylinder/flats interface.

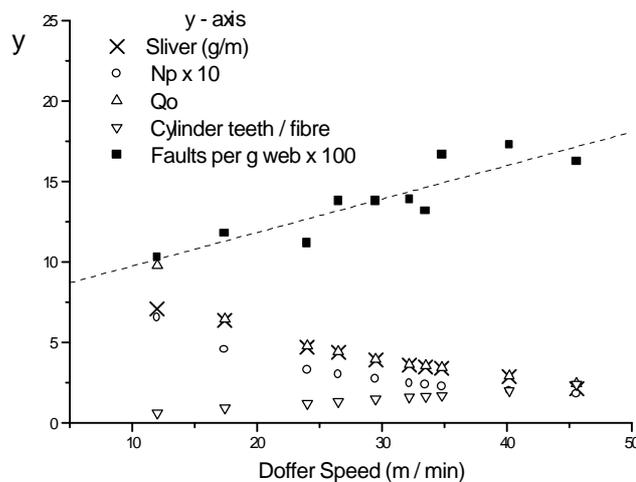


Figure 7: Effect of Doffer Speed on Carding Parameters

Baturin [47] reports an alternative approach to the above in which the following expression was derived for the number of cycles, N_p , under steady state conditions that fibres on the cylinder clothing make pass the flats before being removed by the doffer:

$$N_p = 1 + V_c/KV_d \dots\dots\dots (2)$$

Where K is the transfer coefficient
 V_c and V_d are cylinder and doffer surface speeds (m/min).

Since this gives the number of times the recycling fibre mass is subjected to the carding action, it may be a better indication than P_f of the importance of Q_2 . From the expression, N_p decreases when K increases by increasing doffer speed. Figure 7 shows that for a constant production rate, web quality decreases when N_p decreases with doffer speed, even though the cylinder load decreases and a high number of cylinder teeth per fibre is obtained. The last two parameters are usually taken as indicative of good carding. Figure 8 shows the effect of increased doffer speed and sliver count on web quality and there is a consistent trend which suggests that increasing the production rate by increasing the sliver count, instead of doffer speed, gives better web quality. With regard to sliver irregularity, several investigators [51][52][53][54][55][56][26][33][28][6][47][57] report theoretical and experimental studies showing that increasing the recycling layer, Q_2 , reduces the short-term irregularity.

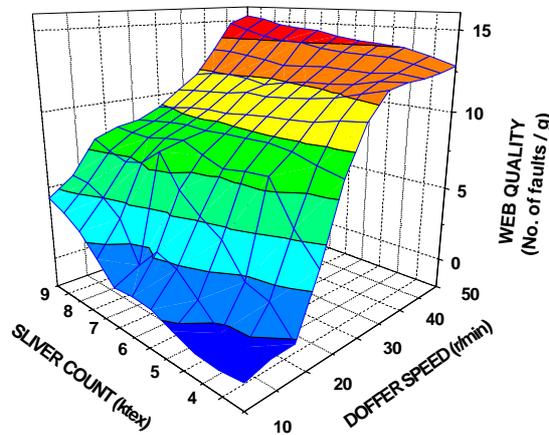


Figure 8: Effect of Doffer Speed and Sliver Count on Web Quality

Karasev [43] attempted to show experimentally the importance of Q_2 by removing it during carding using a suction extractor. It was found that without Q_2 a large proportion of the fibre mass transferred from the taker-in became embedded into the empty teeth of the cylinder clothing. Only the larger tuftlets and groups of individual fibres would then be subjected to the carding and combing actions. Hence, there is a greater chance of small groups of entangled fibres being removed by the doffer. Q_2 therefore acts as a support to new layers of fibre mass being transferred from the taker-in, keeping the new fibre mass at the tips of the cylinder wire teeth and thereby promoting the interaction of tuftlets with the flats and cylinder clothing. This idea, however, does not facilitate an explanation of the mechanism by which fibres leave the recycling layer to form part of the doffer web, Q_1 [27][12][26]. Gupta and et al [2] suggest that the rotating cylinder could be considered as a large centrifuge that would cause fibres, impurities and seed fragments to migrate to the cylinder periphery and thereby make contact with the flats clothing and, presumably, the doffer teeth. However, no experimental verification of this hypothesis is reported.

Many of the authors have reported the effect of machine variables on fibre configurations within the card sliver and several have related yarn properties to the observed configurations. Generally [38] [33][58][59] it was found that for a fixed sliver count increasing the carding rate by increasing the doffer speed, increased the number of minority hooks and reduced the number of majority hooks, irrespective of cylinder speed. However, for a given doffer speed, increased cylinder speed gave the reverse trend for minority hooks, but no clear trend for majority hooks. Baturin[46] and Brown [5] showed that increased cylinder speed decreases cylinder load owing to the effect of centrifugal forces and Simpson [60] showed that increased cylinder speed also increased minority hooks and decreased majority hooks. Bhaudri [61] reports that when

the fibres are forced nearer the surface of the cylinder teeth, either by increasing the fibre load or increasing the centrifugal force on the cylinder, the proportion of minority hooks increases. Simpson [33] found that there was a direct relation between yarn imperfections and increased occurrence of minority hooks and that spinning end breakage rates and yarn imperfection increased with increased card production speed owing to minority hooks [58]. Gosh [38] and Simpson [6] found that heavier slivers had fewer minority hooks. However, the increased draft needed to process the heavier slivers into yarn led to increased yarn imperfections.

Conclusions

1. The taker-in action separates the fed fibre mass into tuftlets and individual fibres. Although it is reported that the taker-in action gives a normal mass distribution of tuftlet sizes, this is speculation. Little research has been reported on the effect of taker-in parameters, fibre properties and the blowroom process on tuftlet size distribution and on the relative proportions of tuftlets to individual fibres.
2. The perceived benefits of combing segments built into the taker-in under-screen and of stationary flats fitted before and after the revolving flats are well known, but only limited experimental findings have been reported to support the use of these attachments. There are conflicting views on the benefits of triple taker-in systems, concerning whether the fibre opening by such systems would give a high misalignment of fibres to the direction of mass flow during transfer to the cylinder and degrade the subsequent carding action. A better understanding is therefore required of the fibre mass transfer from taker-in to cylinder, since the surface speed ratio of these components is seen as a key factor in the proper functioning of high production cards.
3. The cylinder-flats and cylinder-doffer interactions have been well researched. Published findings show that each flat acquires two-thirds of its load at the beginning of its cycle of contact with the cylinder, and that separation of a given tuftlet occurs over a few flats. With regard to clothing parameters and cylinder speed, high teeth densities and lower cylinder speeds gave similar results to the converse arrangement. However, a high teeth density and cylinder speed did not give effective carding. Results showed that high cylinder speeds caused more fibre breakage than high taker-in speed.
4. A high cylinder to doffer speed reduces cylinder load, gives a higher K value and a better web quality. Increasing doffer speed was also found to increase K, but the web quality deteriorated. The reported mechanism of fibre transfer from cylinder to doffer does not adequately explain the effect of the cylinder–doffer speed ratio, or the various reported changes in fibre configuration during transfer. Further work is therefore still needed in this area.

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