An Investigation into the effect of Licker-in Design on Carding Performance

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Submitted in accordance with the requirements for the degree of Doctor of Philosophy

The University of Leeds
School of Design and School of Mechanical Engineering

April 2005

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ACKNOWLEDGEMENTS

My sincere appreciation and gratitude to Dr. Cherian Iype for his guidance and support throughout the PhD including the preparation of this thesis. I also convey my gratitude to Dr. Ali Abbas Dehghani, for his valuable contributions during the experimental work.

I would like to thank Mr. L. G. Ramamurthy, Chairman, Super Spinning Mills Limited, Coimbatore, India who sponsored a major part of this research. I am thankful to Overseas Research Students Awards scheme, UK for the postgraduate research scholarship award.

I gratefully acknowledge the support of Dr. M. R. Mahmoudi in carrying out the experimentation and also for the interesting discussions that were helpful.

Many thanks are extended to all the technicians and staff of Ms. Super Spinning Mills, India who were very supportive in carrying out the experimentation in the Mills. Thanks are due especially to the workshop technicians Mr.Velusamy (India), Mr. Clive Mcburney and Mr. Keith White for their excellent assistance and to Mr.Ashwin Venkatraman for his help in installing the triple licker-in in the University laboratory.

I convey my sincere appreciation to my wife Manjula, Dr. Angelena Jane Moor and Dr. Abraham Nyoni for proof-reading my thesis.

Finally, special thanks to my parents and my wife for their love, moral support and encouragement throughout the completion of this work.

ABSTRACT

Carding is one of the most important preparatory processes in the short-staple spinning of yarn from a raw material such as cotton. The main purpose of carding is to individualise fibres thoroughly so that they can be spun into yarns. Therefore, the quality of the yarns spun and the quality of fabrics produced from them is largely determined by the effectiveness of the carding process. The design of the licker-in zone determines the degree of pre-opening, and so plays a major role in determining the carding efficiency.

This work investigates and evaluates the influence and effectiveness of licker-in design in determining the quality of carded yarns and the fibre configurations in yarn with the two licker-in designs in use today, viz. the single and triple licker-in designs. Two Indian cotton fibre varieties with widely differing characteristics were processed on a commercial high-production card using the single and triple licker-in systems. The quality of yarns spun revealed that licker-in design indeed has a bearing on fibre, yarn and fabric quality. Test results show that whilst the triple licker-in system demonstrated a relative improvement in the yarn quality when processing the medium staple cotton of average fineness, the single licker-in was observed to be more suitable for the longer and finer variety. The analysis of the fibre configuration in yarns indicates that licker-in designs as well as the processing parameters such as licker-in speed and carding rate have an influence on the fibre configuration. Yarns spun using the material processed through the triple licker-in showed more disorder than those of the single licker-in. Finally, an investigation into the fibre opening at the licker-in using high-speed video photography indicates that the degree of opening and the fibre orientation on the licker-in surface before fibre transfer to the main carding cylinder is different between the two licker-in systems. The degree of opening and fibre orientation were also found to depend on the cotton variety, the production rate and licker-in parameters such as speed.

CONTENTS

4. Phase II Experimentation: Fibre Configuration in Yarns

5. Phase III Experimentation: Study of Fibre Flow on the Licker-in Surfaces using High-speed Photography

LIST OF FIGURES

LIST OF TABLES

Chapter 1

INTRODUCTION AND LITERATURE REVIEW

1.1 General Introduction

In the spinning of natural fibres like cotton and man-made fibres, carding remains even today as a key control point, where many yarn and fabric quality characteristics are influenced. Its importance was therefore not overstated in the well-known proverb "Well-carded is half-spun". However, since 1775 when Arkwright patented his card design that formed the basis of the mechanised carding process, the basic principles of short-staple carding have remained substantially unchanged.

Carding today means above all 'economic' carding [1]. The term 'economic' encompasses production rates and production costs (labour costs, energy costs, capital costs and waste) as well as sliver quality, in determining the profitability. The productivity of the carding process has been growing steadily; from a mere 4 kgs per hour output in 1950s [1], to currently outputs of over 100 kgs per hour. The last decade has seen a quantum leap in the productivity levels in the carding process.

Figure 1.1 shows the growth in card output rates since 1970-2000.

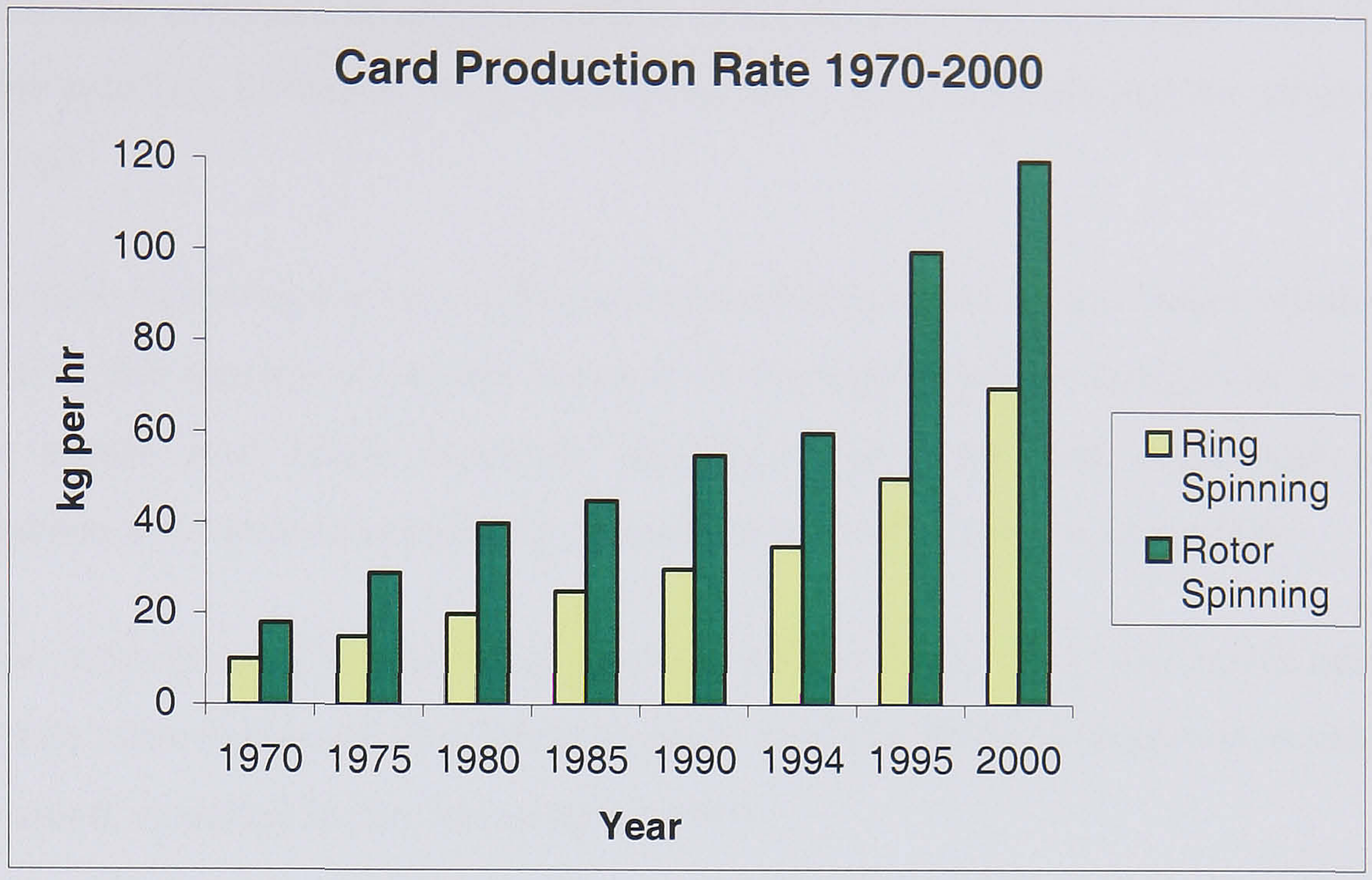

Figure 1.1 - Card production rate 1970 – 2000 [2]

Several factors have contributed to the increase in productivity of the carding process. The primary factor being precision engineered construction that permits closer settings and higher speeds; new and improved metallic alloy clothing for the cylinder, flats and doffer; the introduction of pre and post opening segments over the cylinder and the introduction of the triple licker-in system.

It has been generally accepted over the last decade or so that further developments in clothing design can bring only small increases in productivity. Attempts however, have been made to increase the productivity by presenting a more open material to the cylinder-flats zone, so that the work at the flats/ cylinder interface could be greatly reduced, thereby improving the carding efficiency. This has led to the development of stationary pre-opening elements for the licker-in zone and for the pre-carding zone at the back of the cylinder and the development of multiple licker-in arrangements.

There have been several licker-in designs proposed over the years and the success of the new triple licker-in design by Truetzschler, although primarily designed for processing coarse (short and medium staple) cotton, demonstrated the importance of proper opening of the feed-material in the licker-in zone [3]. There has been some anecdotal evidence of adverse effects of triple licker-in processed fibre on yarn and fabric quality, however, very little published work concerning its performance is available.

This research investigates the influence and effectiveness of the licker-in design in determining the quality of carded yarns with the two licker-in designs in use today, viz. the single and triple licker-in designs. The aims and objectives of this investigation are more conveniently discussed after the literature review.

The basic principles of the carding process, its evolution over the years and most importantly, the design of the licker-in zone and the fibre processing in this zone are discussed in detail in the literature review.

1.2 Carding

1.2.1 Definition

According to the dictionary [4], 'Card' means a wire-toothed brush or a machine fitted with rows of wire teeth, used to disentangle fibres, such as wool, prior to spinning. The word 'card' was derived from the Latin word 'carduus,' meaning thistle. A pair of hand cards, consisting of thistles fixed on a wooden frame was used in the fifteenth century to comb out and clean cotton and wool fibres before spinning [5].

1.2.2 Objectives of Carding

The main or the fundamental objective of the carding process is to open up the raw material (flocks) separating the fibres till they are more or less at the individual level. During the carding process, foreign matter like seeds and dust are conveniently eliminated and the quality of the output (sliver) of the card is enhanced due to the elimination of neps and short fibres.

The tasks of the carding machine can thus be summarised as follows [5, 6]:

1. To open the raw material to individual fibres.
2. To remove the foreign matter like seeds, sand etc.
3. To disentangle/remove neps.
4. To eliminate dust and a certain amount of short fibres.
5. To achieve a greater degree of blending.
6. To re-assemble the fibres into a form suitable for further processing and
7. To achieve a certain degree of longitudinal order.

In the card, the degree of cleaning of foreign matter is quite high, it ranges between 80-95%, while a large amount of micro-dust present in the feed material is also removed [1]. In modern carding machines, the degree of disentangling of neps could be up to 85 % depending on the cotton used [7].

1.3 Technological construction of a short-staple carding engine

1.3.1 Material passage through a carding machine

The simplest illustration of a traditional card is represented in Figure 1.2. The scutcher lap* is slowly unravelled by frictional contact with a lap roller. The lap sheet passes in between a feed plate and a heavily weighted feed roll (80 or 100 mm diameter), which thrusts the lap slowly into the operating range of a saw tooth covered roller called 'licker-in' or 'taker-in'.

* Scutcher lap - The end product of the Blow-room process. A sheet of cotton or any raw material rolled to form a package known as 'lap'.

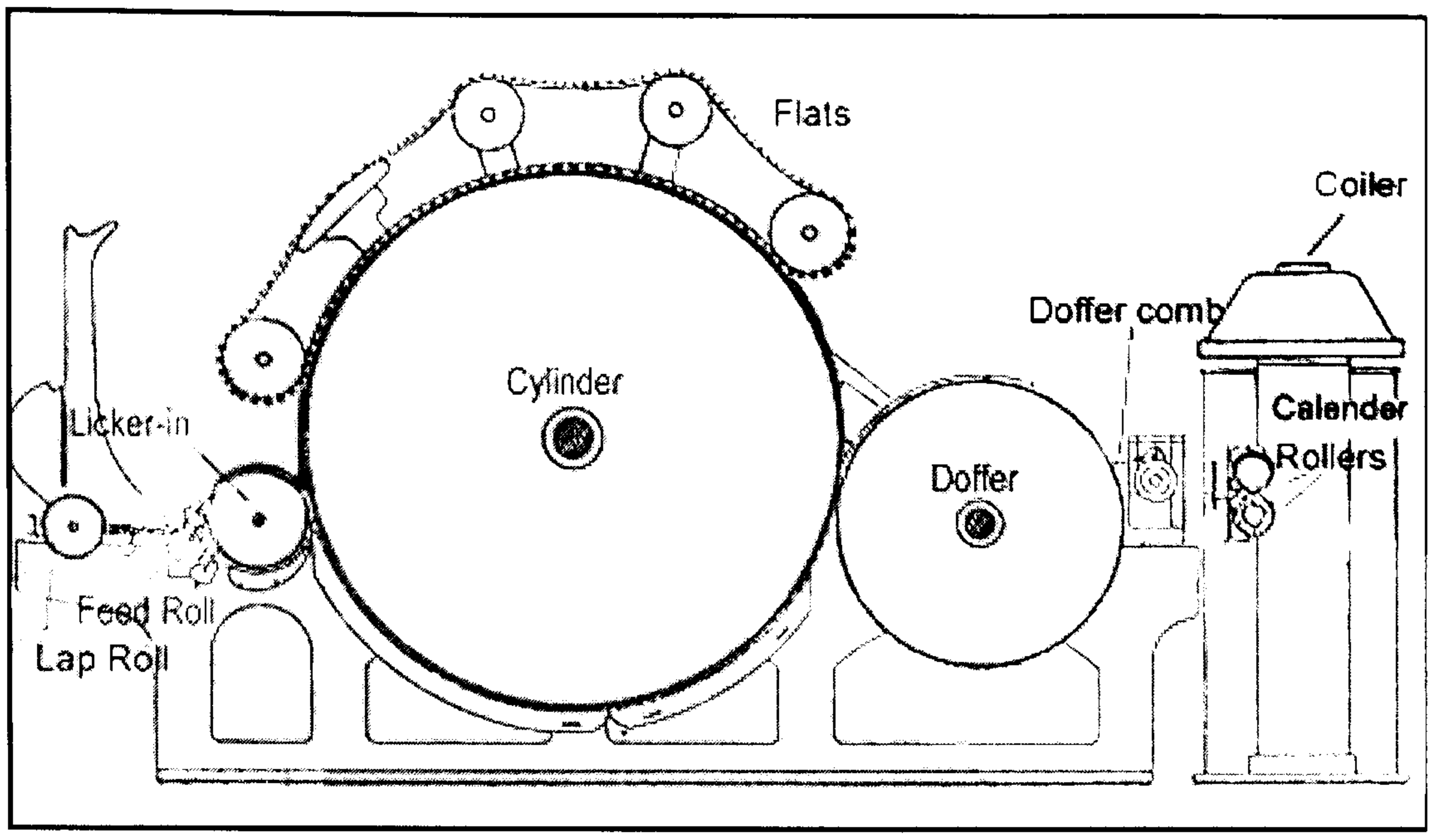

Figure 1.2 - Traditional Carding Machine [5]

1.3.1.1 Licker-in zone

The licker-in, usually measuring about 250 mm in diameter, runs at a much higher surface speed (>10 m/s) than the feed roller (about 0.05 m/s max). The aggressive combing action of its teeth detaches the fibres and tufts from the feed lap. Due to an effective opening, a significant amount of heavy foreign matter along with some lint is ejected under the licker-in with the help of knives, while the fibres and tufts are carried forward by the licker-in teeth toward the cylinder.

1.3.1.2 Cylinder-Flats zone

The faster running Cylinder (20-45 m/sec), measuring about 1000 or 1290mm Ø and having a greater density of metallic wire clothing than that of the licker-in, strips the fibres from the licker-in surface. The cylinder passes the material through a series of flats; some stationary and several moving. The stationary flats are clothed with rigid metallic wire clothing, while the moving flats are generally clothed with flexible fillet clothing. The wire points on the flats clothing are positioned so that they oppose the points of the cylinder clothing, with a very small distance separating the clothing of the cylinder and the flats. This results in an intensive opening or combing known as 'carding action'. Since the linear speed of the flats (just a few inches per minute) is vastly lower than that of the cylinder, the fibre tufts tend to get accumulated at the flats; only to be progressively opened into individual fibres as they pass through flat /cylinder zone and the individual fibres are removed by the fast moving cylinder. During the process, the clothing of the moving flats collects some of the fibres and trash particles as they leave the cylinder. The direction of movement of the flats could be either in the direction of the cylinder as in traditional cards or in a direction opposing the cylinder direction as in some modern cards; which is claimed to improve the carding quality.

1.3.1.3 Doffing zone

The fibres on the cylinder, now individualised and relatively well oriented, are transferred to a small cylinder known as the 'doffer' covered with metallic wire clothing and measuring about 500 or 690 mm Ø. Its surface speed is several times lower than the cylinder (10 to 20 times slower). The mechanism of fibre transfer to the doffer will be discussed in detail later.

A metallic wire clothed stripping roller rotating in opposite direction to the doffer removes the fibrous web off the doffer. The web then passes through two smooth hardened steel crush rollers arranged one over the other, which crush and remove any trash particles remaining in the web. The web from the crush rolls, via a web take-off system, passes through a funnel known as a 'trumpet' where it is condensed and then through a pair of calender rollers. The resulting sliver is then taken through a coiler tube before being deposited into a can.

1.3.2 Purpose and function of the main card components

1.3.2.1 Card feed

Modern cards are directly fed from the blow-room using pneumatic chutes. While the card can cope with inherent variations in fibre properties, variations in the feed with respect to mass per unit area and openness will ultimately be reflected in a deterioration of the final sliver quality [6]. In card feeding installations, the material level and distribution across the width of the feeding chutes are precisely controlled to ensure that the weight variation is kept to a minimum and flocks are well opened before they are fed. For improved opening, most of the chute designs in use today have an integral opening arrangement that incorporates an opening roller.

The feed roller in conjunction with a feed plate feeds the material to the licker-in roller at a constant rate. In modern carding installations, the feed plate has sensors to monitor the thickness of the feed and the speed of the feed roller is altered to ensure that the quantity fed in is constant.

The feeding to the licker-in could be done in two ways.

1. First method is the conventional or counter feeding, in which the feed roller moves the feed material on a feed plate as shown in the figure 1.3. The feed material, gripped by the feed roller, is supported at the feed plate nose while the licker-in combs away the material.

2. The second method known as concurrent feeding, which is used in some modern cards, is to operate the feed roller so that its surface moves in the same direction as the licker-in, as shown in the figure 1.4 and is unlike the conventional method, which has a counter-directional feeding. This second method is claimed to offer a gentler opening action and thus a potential reduction in fibre damage [6].

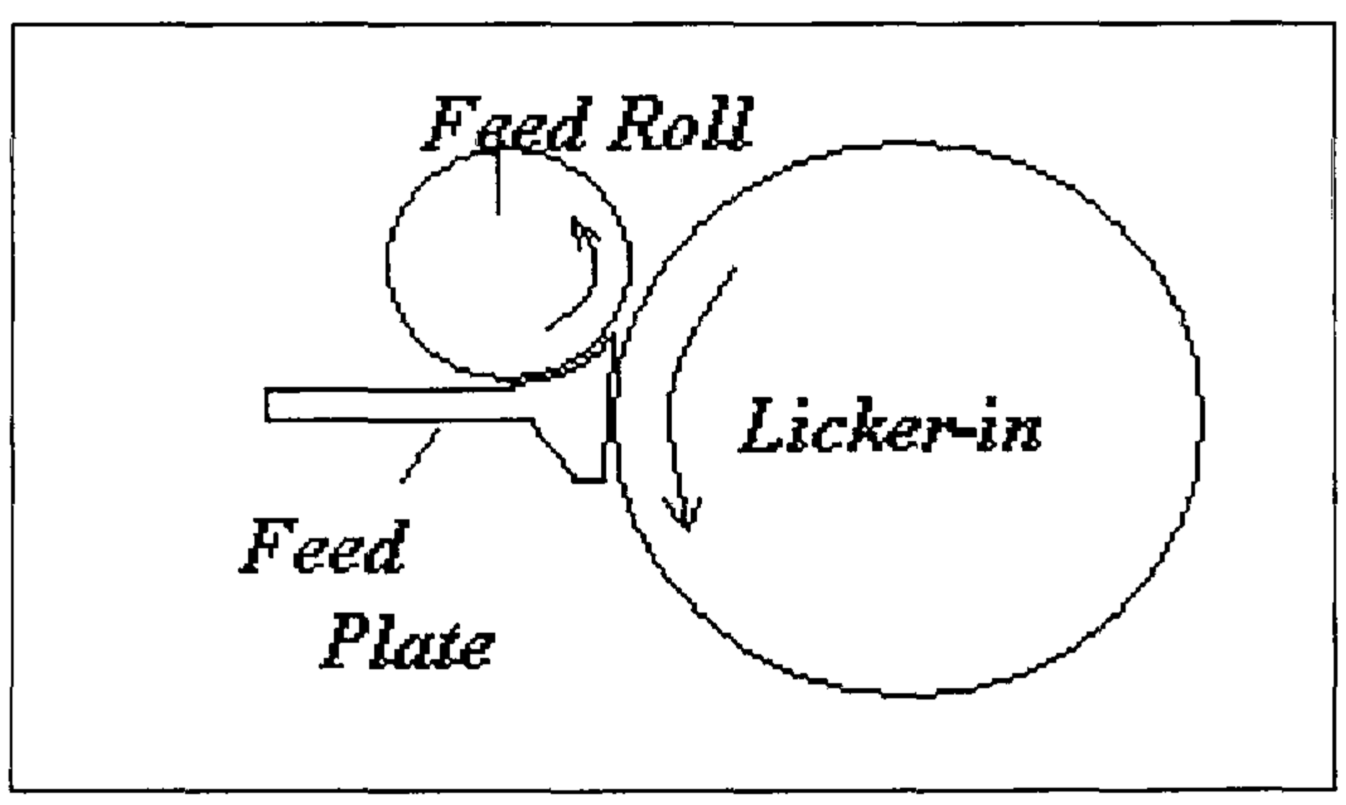

Figure 1.3: Counter Feeding

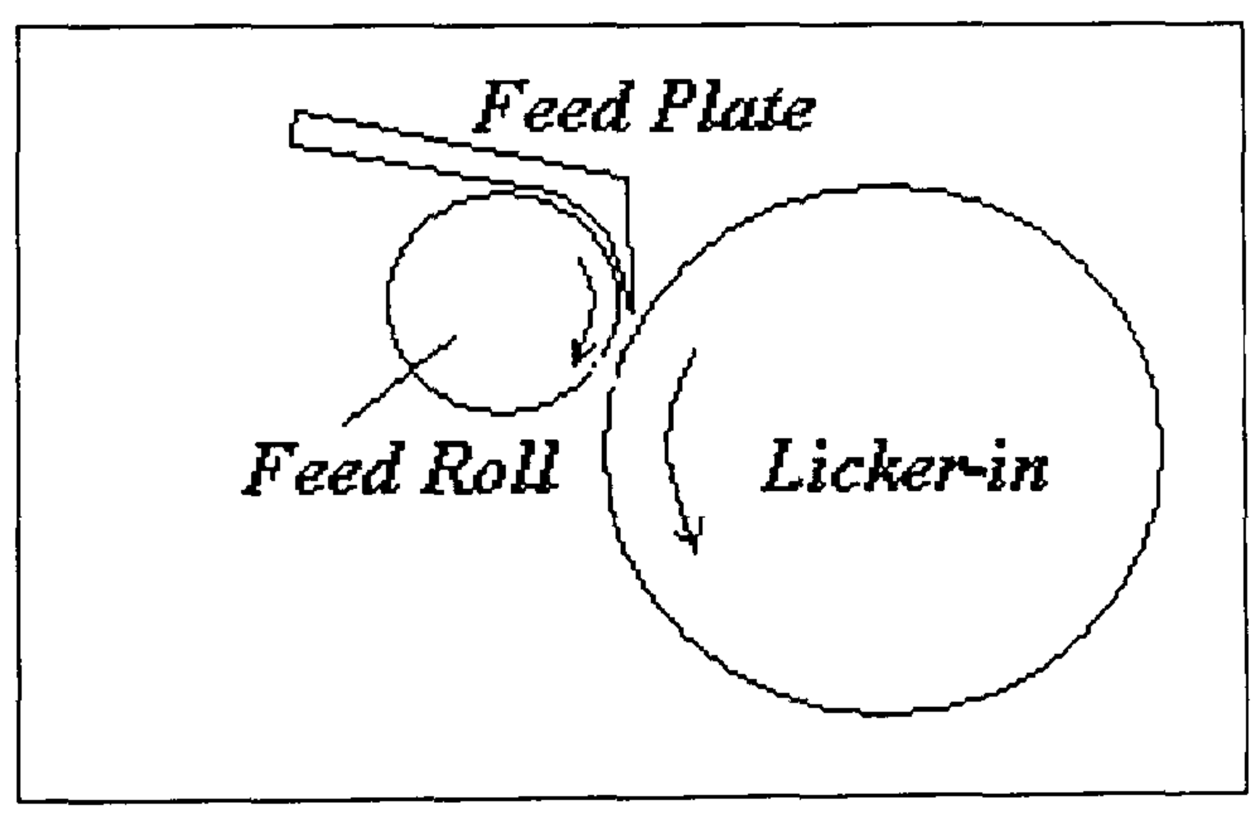

Figure 1.4: Concurrent Feeding

1.3.2.2 Licker-in

The saw-tooth clothing of the licker-in penetrates the disordered and compressed fibre mass feed matt, while it is being strongly nipped by the feed plate /feed roller arrangement. The speed of the licker-in in high-production cards with a 250 mm diameter licker-in, could be in the range of 800-1500 rpm for cotton and 600 rpm for synthetic fibres [6]. Therefore the peripheral speed of the licker-in could be more than 500 times greater than that of the feed roller. The fibres and flocks are rapidly accelerated to the licker-in speed as the larger tufts are reduced to small micro-tufts and the entrapped extraneous matter within them is released underneath the licker-in surfaces because of the centrifugal force. The cleaning function is based on a sorting action using the interaction between centrifugal force and airflow to separate fibres from contaminants [3]. A modern licker-in arrangement is shown in figure 1.5.

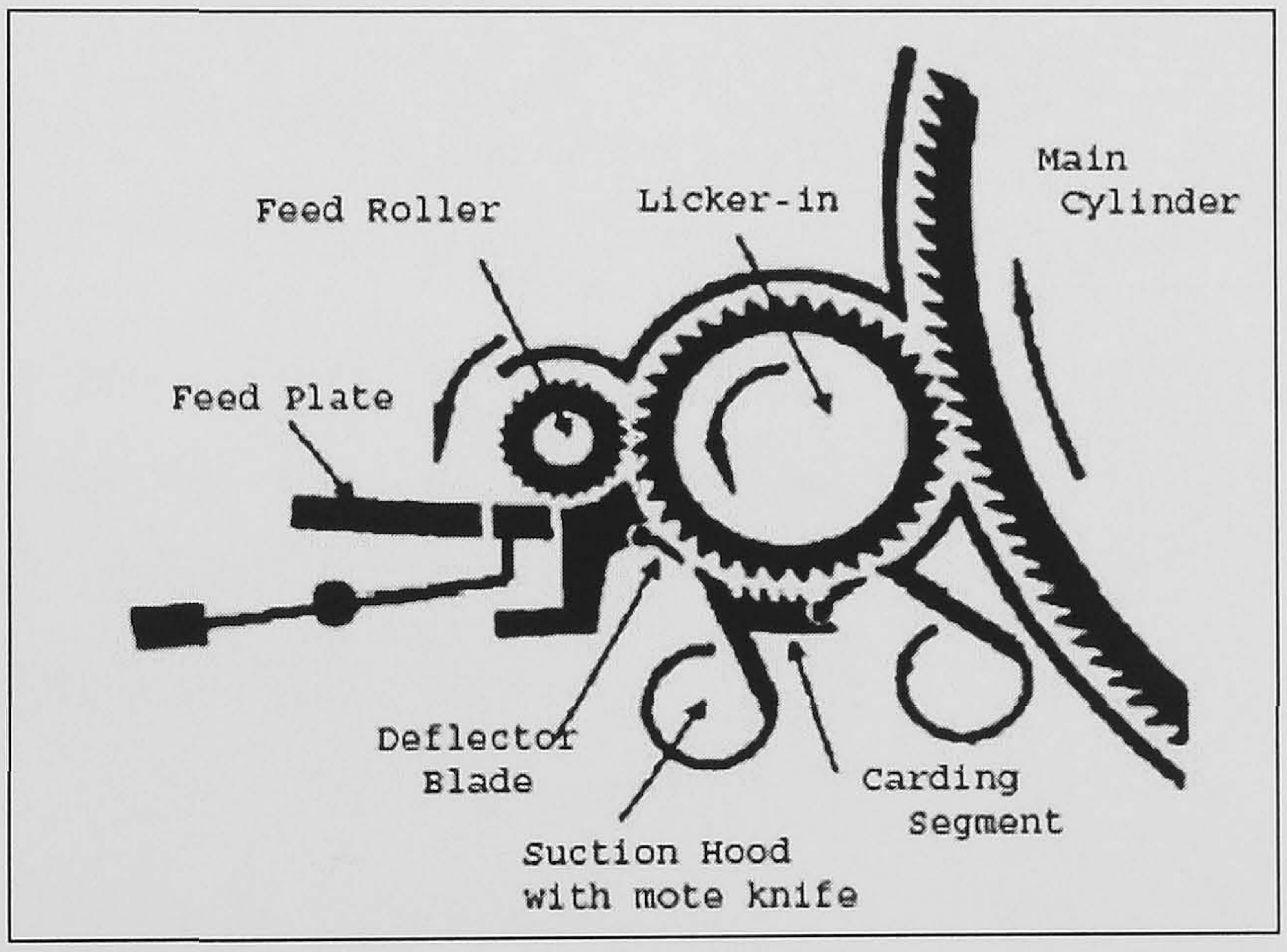

Figure 1.5: Modern Licker-in (Truetzschler design) [6]

Modern licker-in arrangements also use opening segments (stationary segments with metallic wire clothing) to further open up the tufts, as can be seen in figure 5. The tuft size reduction at the licker-in zone significantly reduces the load on the cylinder-flats zone. In one study done at the University of Leeds [8], it was found that a substantial separation occurred at the licker-in (due to the combing action at the feed roller nip) such that nearly half of the fibres were individual fibres.

Higher licker-in speeds naturally lead to increased opening. However, this could be at the cost of fibre length and a certain amount of good fibre loss. Industrial experience has shown that for long and slender fibres, the licker-in can result in a significant staple reduction if speeds and settings are not chosen appropriately.

1.3.2.3 Cylinder-Flats zone

It is one of the ironies of the cotton system that the fibre properties required for the most efficient roller and apron drafting, and spinning are almost exactly opposite to those required for the most efficient carding [9]. A long finer fibre with relatively higher coefficient of friction is required for the most efficient roll or apron drafting, while relatively short, coarser fibre with low friction is required for the most efficient carding.

The action between cylinder and flats has been debated over several decades. While experts agree on a few points, there is still ambiguity about what is actually happening between the cylinder and flats. Several hypotheses have been proposed, and one such hypothesis offered by Crosrol Ltd [10] is presented here.

The tufts, broken down partly through combing by the taker-in at the feed plate, are re-distributed on the surface of the cylinder in accordance with the relative surface speed of the two rollers. The consecutive stages of cylinder to flat interaction are shown in Figure 1.6.

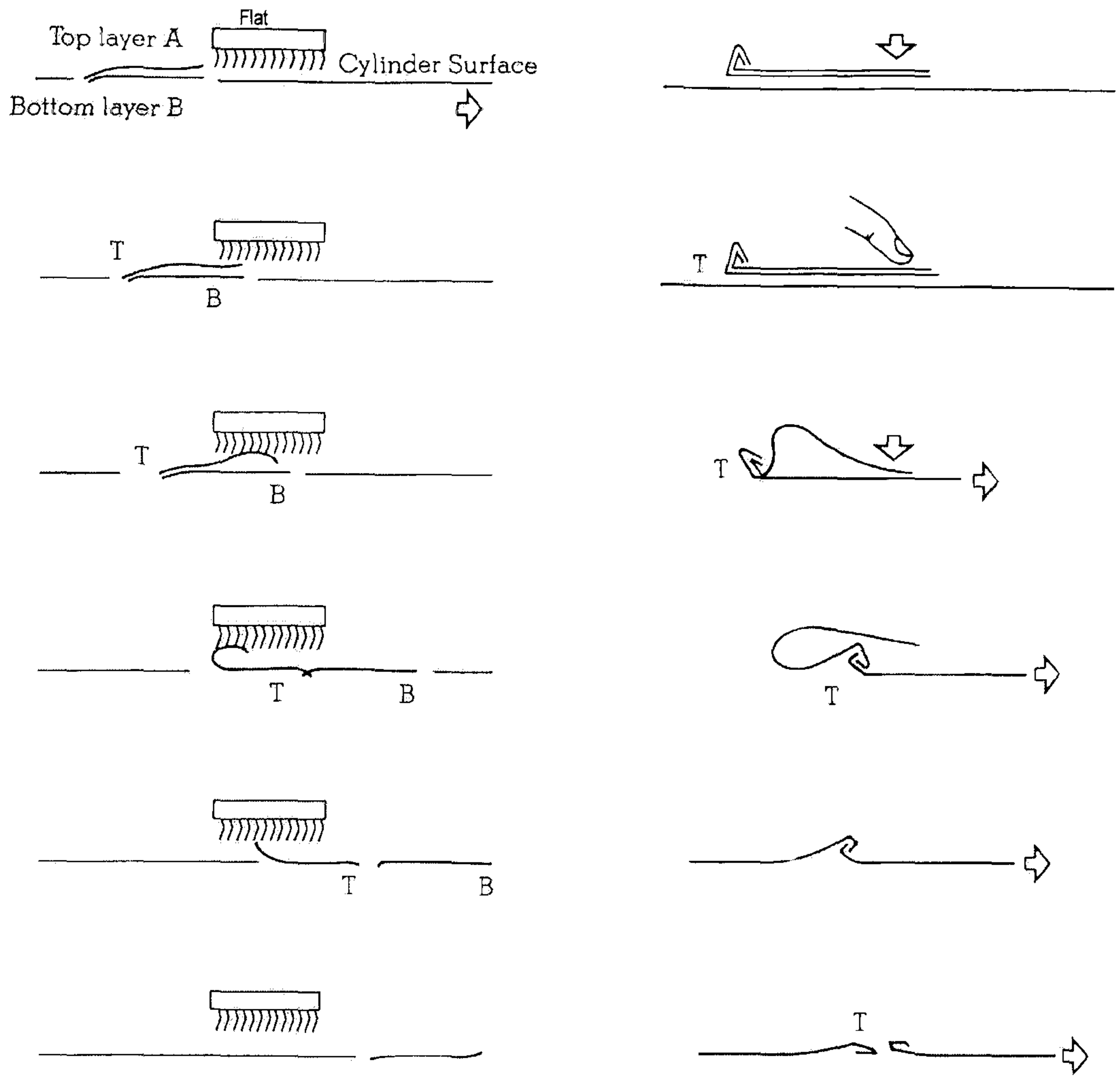

Figure 1.6: Cylinder-flat interaction [10]

It is assumed here that the tuft is lying lengthwise on the cylinder surface and that it has two layers, top and bottom. The bottom layer is the one that is under the direct or indirect control of cylinder wires. The fibres protruding from the cylinder wires or lying above the cylinder surface are assumed to constitute the top layer. As the tuft is taken into the area between the cylinder and flat, the leading end of the protruding top layer is arrested, while the back end of the top layer is still in contact with the bottom layer by adhesion or entanglement. As the cylinder carries forward this tuft, the top layer is peeled off from the bottom layer. Subsequently, the trailing end of the top layer, after it has been carried across the setting gap and has become a leading end, hangs into the path of the cylinder, which combs it.

In the course of combing, all fibres which are not embedded in and held firmly at one end by the flat wires or lying cross-wise in the tuft, are combed out and pulled back onto the surface of the cylinder. Tufts and fibre agglomerations are in this way broken down into smaller units. The fibres remain exposed to the action of the cylinder wires until combed and carried away by the cylinder. Thus the action between flats and cylinder wires on the fibres is repeated until the cylinder has combed back all fibres caught by consecutive flats, the wires of which can only retain dirt, fluff, short fibres and such long ones that are not protruding.

On a modern card, before the tufts enter the cylinder-flats zone on the cylinder, they pass through a 'pre-carding zone'. This zone consists of a series of stationary opening segments or flats with saw tooth clothing. Introduction of these flats (both in pre-carding and post carding zones on the cylinder) along with trash ejection arrangements (Figure 1.7) have resulted in significant improvements in carding quality and productivity. These flats further open up the micro-tuftlets in the incoming material and thus a significant amount of trash is ejected from the cylinder before the material enters the actual carding zone. Consequently, modern cards permit the use of flats with more filling depth and a higher number of points in a finer wire quality [11].

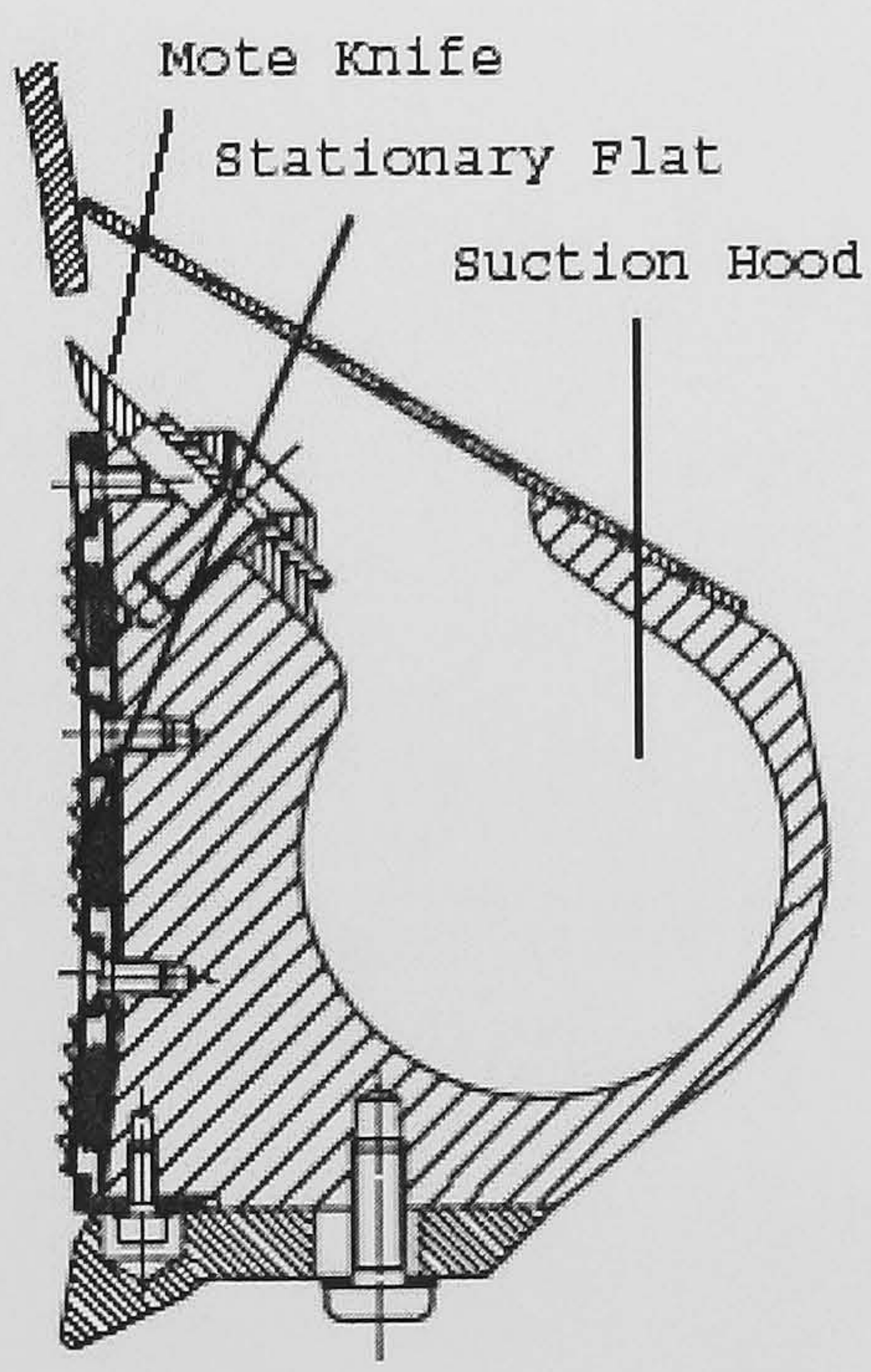

Figure 1.7: Stationary flats with suction [12]

1.3.2.4 Doffer

The main function of the doffer is to take off the fibres that lie more or less evenly distributed between the cylinder wires, and to condense them so that they constitute a coherent web. Fibres at the front of the cylinder are kept pressed down by the front plate. When they come out of the bottom edge of the front plate, they suddenly rise with an expanding air current and become ready for transfer to the doffer [13]. The fibres are transferred due to a complex interaction of forces on the fibres, which result in a condensation to form a web. The doffer diameter, setting to the cylinder, doffer wire population, tooth height and tooth angle all together have an effect on transfer efficiency and subsequent sliver quality [14]. The complex interaction of the forces on the fibre and the rapid movement of fibres at the transfer point make it difficult to observe the mechanism of transfer. However, based on the evidence available, certain conclusions have been drawn regarding the mode of transfer.

a. Fibre transfer becomes effective after build up of 'an operational layer' of a certain thickness on the cylinder.

b. Fibres make an average of 4 or 5 revolutions on the cylinder before being transferred to the doffer. Some fibres get transferred during the first few revolutions, but the rest may take up several revolutions [15].

c. Fibres can undergo reverse transfer between the doffer and the cylinder. This phenomenon has been proved experimentally by stopping the doffer with a certain layer of fibres and it was found that the cylinder takes away the fibres from the doffer surface.

By reducing or increasing the doffer speed, the thickness of the fibre web collected by the doffer increases or decreases accordingly. At higher doffer speeds, there is little time available for the cylinder to take back some of the material collected on the doffer and hence the doffer acts as a more efficient doffing device.

Though the arrangement of the clothing between the cylinder and the doffer is meant for fibre transfer, there is also a CARDING ACTION between them; though it is different from cylinder/ flats interaction. This 'working' or 'carding action' between the cylinder and the doffer is due to firstly, the configuration of the clothing of the cylinder and the doffer (their clothing oppose each other) and secondly, the greater surface speed of the cylinder over the doffer. Obviously, the 'working or carding' action is reduced at higher doffer speeds and vice versa.

The widely accepted view of the fibre distribution within the card under steady-state conditions is illustrated in Figure 1.8 [16].

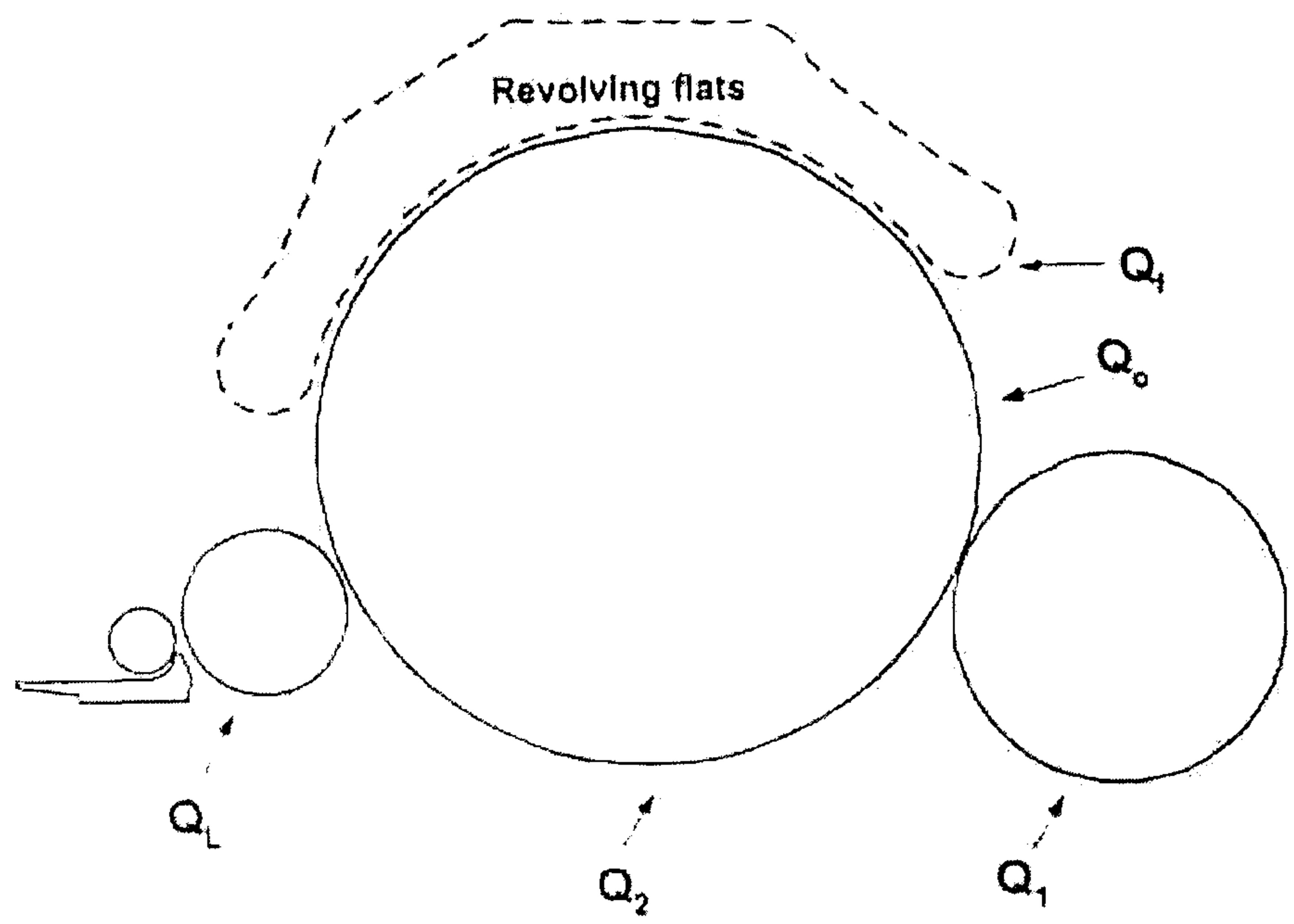

Figure 1.8: Fibre distribution within the card [16]

Q_L- Material on Licker-in
Q_f- Waste removed by Flats
Q_o- Material on cylinder before transfer
Q_2- Operational Layer
Q_1- Web on doffer
Transfer factor = Q_1/Q_0

There appears to be an optimum number of times that the fibres pass through the cylinder-doffer set zone before finally transferring to the doffer [14]. The fibre transfer factor is of the order of 0.2 to 0.3 [6], which means that some fibre remains on the cylinder and is termed as the operational layer (Q_2). Karasev [17] showed experimentally that without an operational layer Q_2, a large proportion of the fibre mass transferred from licker-in becomes embedded into the cylinder clothing. Only the larger tuftlets can then be subjected to the carding action and hence there is a greater chance that smaller tufts may be transferred to the doffer without being subjected to any carding action. He concluded that it is important to have a certain amount of operational layer to be present on the cylinder, which would mean that the fibre transfer from cylinder to doffer should not be greater than a certain optimum.

1.3.2.5 Sliver formation and delivery

The post doffer arrangements are mainly meant for efficient doffing and smoother sliver formation. Nevertheless, they are crucial in modern high production cards, as sliver delivery speeds can be up to 300 metres per minute. As mentioned earlier, a pair of smooth hardened stainless steel rollers also known as crush rollers crush-off the remaining vegetable matter in the sliver. However, it has been observed that the yarn strength drops if the crushing is excessive.

The methods used for condensing the web into a sliver can be classified either as active or passive formation. In the active formation method, two endless belts rotating at the same surface speed as the crush rollers, also known as aprons, condense the material to form a sliver. In passive formation, a highly polished, specially designed condensing channel set closer to the crush rollers, condense and form a sliver. Both designs are used in high-speed cards.

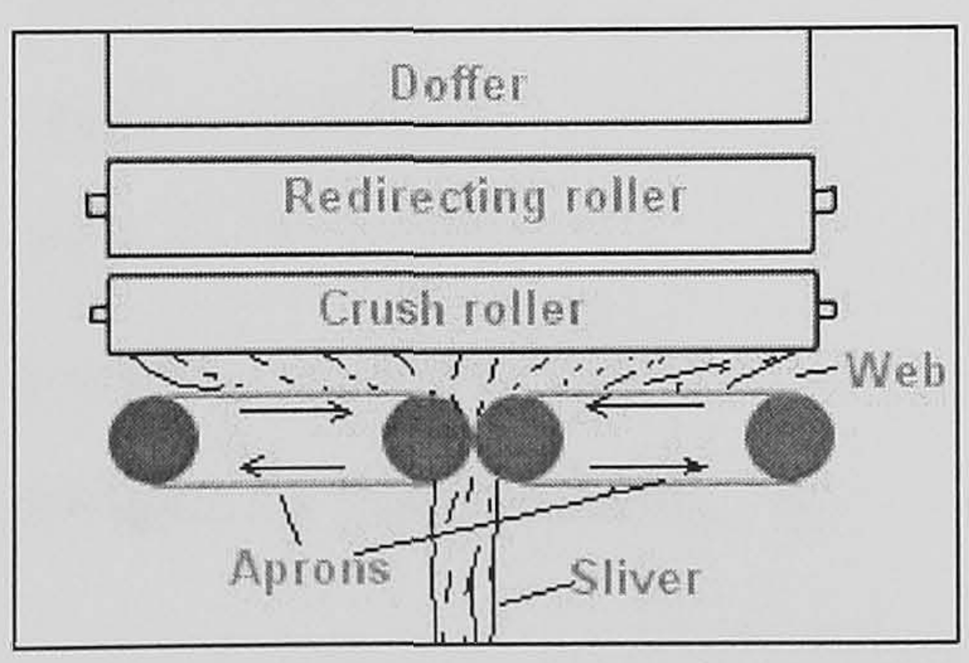

Figure 1.9: Active web formation

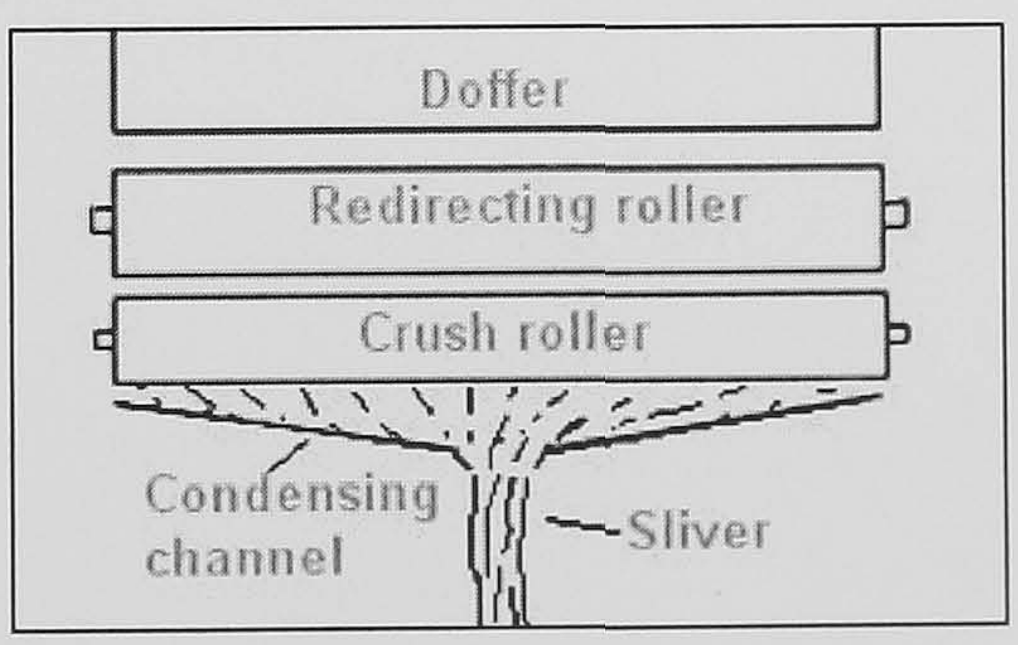

Figure 1.10: Passive web formation

1.3.3 Design and function of card clothing

The metallic card clothing used in the cards plays a major role in ensuring efficient carding in terms of both quality and productivity. Development of new clothing contributed significantly to the increase in card quality and productivity over the years [6]. Currently there are several types of clothing available, each with a specific purpose and therefore, when choosing the clothing several factors must be considered. These factors include: the type of card; speed of the cylinder; the licker-in; production rate; raw material type and fibre characteristics [6]. Therefore, the mill has to choose clothing according to its specific requirements to achieve the targeted quality and productivity levels.

The types of clothing in use today can be divided in to three categories:

1. flexible clothing.
2. semi-rigid clothing.
3. rigid clothing.

Flexible and semi-rigid clothing is presently used only for the flats, while the rigid metallic all steel clothing is used for licker-in, cylinder, doffer and stripping roller. Three decades ago, flexible clothing for cylinders and doffers was replaced by all steel clothing. The main reasons for this replacement were the fibre and trash loading of flexible clothing, which needed to be stripped frequently to maintain the quality of the sliver, and their unsuitability for higher cylinder speeds [18]. The geometric parameters relating to the card clothing are as follows:

1. point density.
2. tooth pitch (P).
3. rib thickness (t).
4. carding angle α and
5. height of the clothing (H)

Figure 1.11 shows the typical geometry of metallic card clothing.

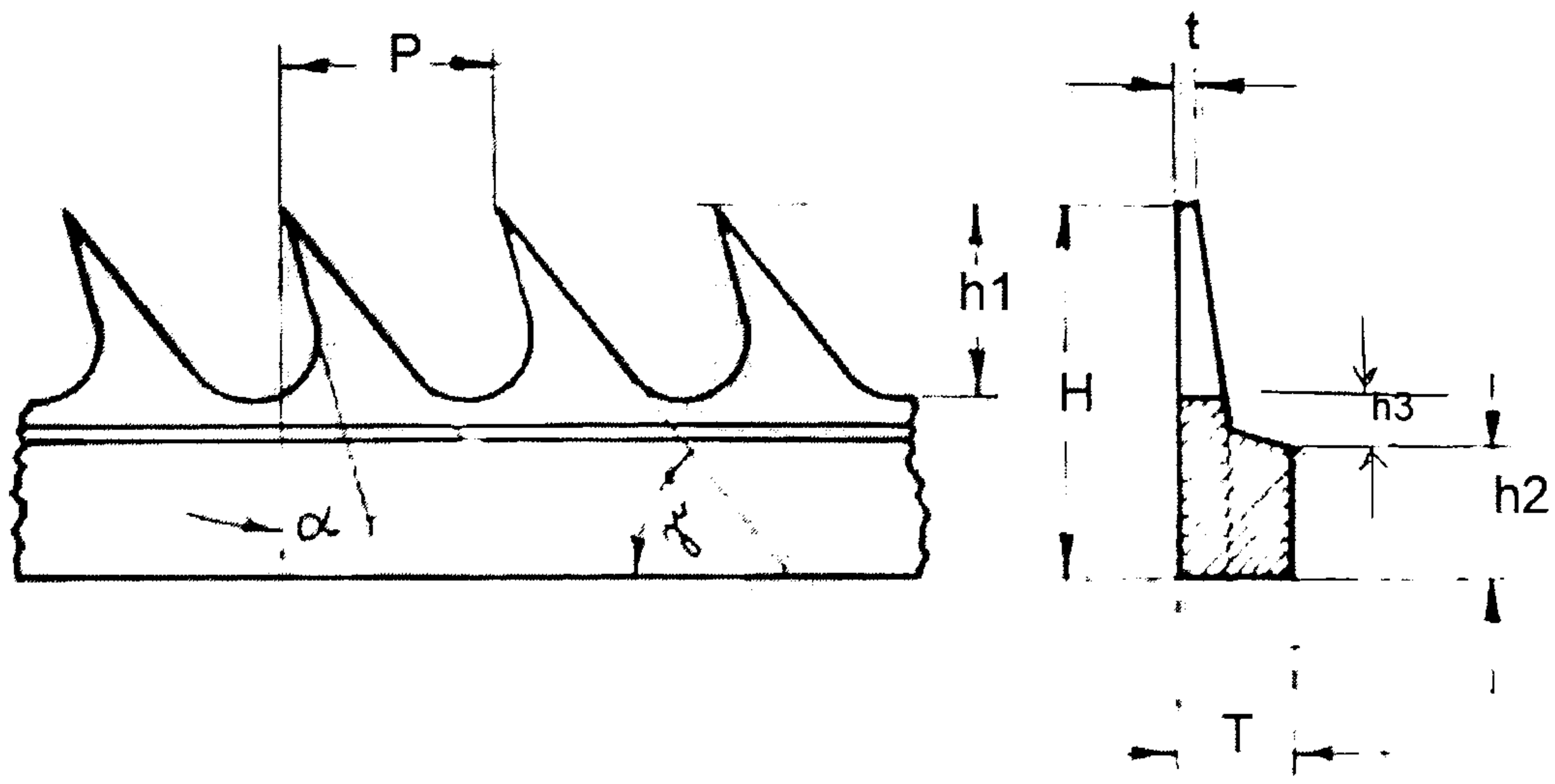

Figure 1.11: Geometry of metallic wire clothing

1.3.3.1 Point density

Point density can be defined as the number of points per unit surface area, i.e. per square cm or square inch. In general, the higher the point population on the cylinder and the flats, the better is the carding effect. However, above an optimum point density, the positive influence can become a negative one, the optimum being dependent on the raw material. Coarser fibres need fewer points and finer fibres more points [6]. Higher point density of the card clothing on the doffer increases the doffing efficiency due to an increase in its retaining capacity.

1.3.3.2 Tooth pitch and rib thickness

Tooth pitch and rib thickness determine the points density. The wire geometry commonly used in modern short staple metallic card clothing is given in Table 1.1 [12]. The flats use a wire point density in the range of 240 to 550 points per square inch (ppsi).

Table 1.1: Card Wire Specifications

Part	Point Density PPSI*	Carding Angle (degrees) α	Rib thickness (mm) T	Pitch (mm)** P	Tooth height (mm) H
Licker-in	24 – 41	-10 to +15	NA	5.0 – 8.5	5.0 – 5.5
Cylinder	395 – 1080	15 to 40	0.4 – 0.9	1.5 – 1.8	1.5 –3.2
Doffer	278 – 395	25 to 45	0.85 – 1.0	1.8 – 2.3	4.0
Stripper roller	107 – 206	-28 to -30	1.0 – 1.8	3.0 – 3.5	3.5 – 4.0

* Points per square inch

** Calculated from the data given in Graf website [12].

1.3.3.3 Carding angle and wire height

The efficiency with which the fibrous material is opened in the taker-in assembly depends to a large extent on the parameters of the feed table and those of the saw tooth clothing of the licker-in [19]. The higher the carding angle, the greater is the hold on the fibres. The carding angle could be negative or positive, depending on the application. Licker-in clothing meant for man-made fibres use a negative or neutral angle, while those meant for cotton use a positive angle. The cylinder uses a larger carding angle with a low wire height. Greater carding angle gives greater holding and retaining capacity while the lower wire height keeps the fibres in the active carding zone. A more acute angle of doffer wire pulls fibres deeper into the wire interspaces, which similarly increases the doffer's retaining capacity leading to better doffing efficiency.

1.3.3.4 Other special design features

An important design feature of the modern cylinder clothing has been the elimination of the space available for the trash particles to embed in between the adjacent rows of wires (known as 'No Space for Loading' profile). This design uses a shallower tooth depth than the standard one, and the free blade area (Figure 1.11, h3) is eliminated. This special design has contributed to eliminating the need for stripping of the cylinder wire altogether.

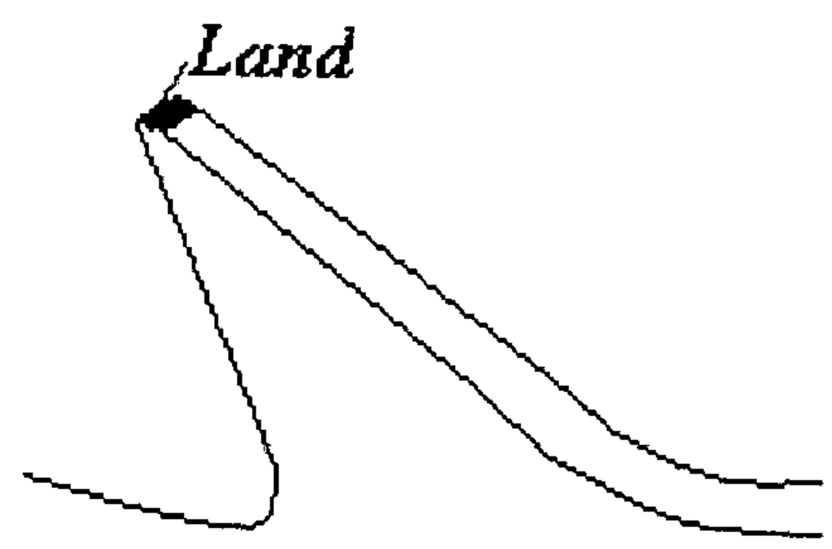

Figure 1.12: 'Land' of metallic clothing

Another important aspect of a metallic wire is known as the 'land' or the area at the tip of the teeth (Figure 1.12). The wire for the cylinder is cut in a special way so that the tip is very sharp and the land area is extremely small. An increase in the size of the land or wire tip area reduces the carding efficiency. Further, such clothing also has a low wire height and therefore grinding of such fine clothing is not recommended. The flexible fillet clothing of flats however needs to be ground frequently to maintain sharp tips on the wire points. Doffer wire, which does not wear so rapidly, is ground whenever it is necessary, to ensure proper transfer of fibres from the cylinder.

1.3.4 Evolution of carding technology over the years

An excellent review of the progress in card design is given by Bruno Wolf [20].

The patent of Lewis Paul was the first one to use the principle of a clothed drum working against a similarly clothed trough. However, a nearly complete card with a licker-in, cylinder, stationary flats, doffer, doffer comb and web detaching rollers along with sliver delivery arrangement can be seen in Arkwright's patent of 1775. The cards with stationary flats needed to be taken out periodically and cleaned [20]. Scotsman James Smith invented the self-cleaning revolving flat card in 1834. The revolving flats card built in 1857 closely resembled the cards built one hundred years later. The evolution of carding was gradual up until the end of the 1950s. Around this time, there was a great deal of activity on the part of machinery manufacturers in the carding sector and attempts were made to move away from the traditional card design [21].

In the 1970s, some interesting designs were seen and among them was a design by Bettoni, who increased cylinder diameter and placed one set of flats above and one below the cylinder. During this time Carminati-Zinser produced a design, which replaced flats with a number of small, clothed rollers [20].

Quality and performance of the cards was further improved by arranging two cards in tandem [20] and Bettoni combined 3 small cards in tandem. There were cards that used multiple licker-in arrangements like the double licker-in arrangements of SACM and Schubert and Salzer and also a triple licker-in design of Schubert and Salzer that emerged during the 1970s. These licker-in designs will be discussed later in the review. To increase the production per card, in their Supercard KU 12, Schubert and Salzer also increased the card width to 1.5 metres from the traditional 1 metre width [5]. They also provided an option of having two deliveries instead of one, by dividing the web.

In studies done at the Shirley Institute [22], it was found that the carding power of the card increased as the cylinder diameter was decreased and it peaked at 40 inches. They also found that the optimum arrangement to be 10, 40 and 20 inches for the taker-in, cylinder and doffer respectively. These dimensions became the standard feature of Crosrol cards, both single and tandem. Recently, Rieter introduced a 40-inch diameter cylinder in their C60 card, with the claim that it removes more trash in the carding zone (cylinder/flats) than in cards of conventional design that used a 50-inch diameter cylinder. This is due to a 50% increase in centrifugal forces resulting from the use of a smaller cylinder diameter and higher cylinder speeds [23]. It is also interesting to note that Rieter have also used 1.5 metre wide cylinders (as Schubert and Salzer) in their new card. Rieter also contends that the small diameter of the cylinder reduces the effect of temperature fluctuations on the size of the carding gap, thus permitting narrower settings without running any risk [23].

Although it did not become as popular as people thought it would be, tandem or double carding did make its mark, especially for rotor spinning. Tandem carding involves carding the web of the breaker card again using one more set of cylinder and flats arrangement. Hence, it was essentially two cards combined into one. Good quality improvements and improved spinning performances were reported, especially in rotor spinning because the slivers were clean, with a reduction in faults like neps. It was also found that the orientation of fibres in the tandem carded sliver was better with a reduced number of hooks and the waste in combing process could be reduced [9]. However, due to the increased maintenance, space and power requirements, it did not achieve wider market acceptability.

Figure 1.13 illustrates the increase in card productivity since the 1950s along with the technological developments in carding.

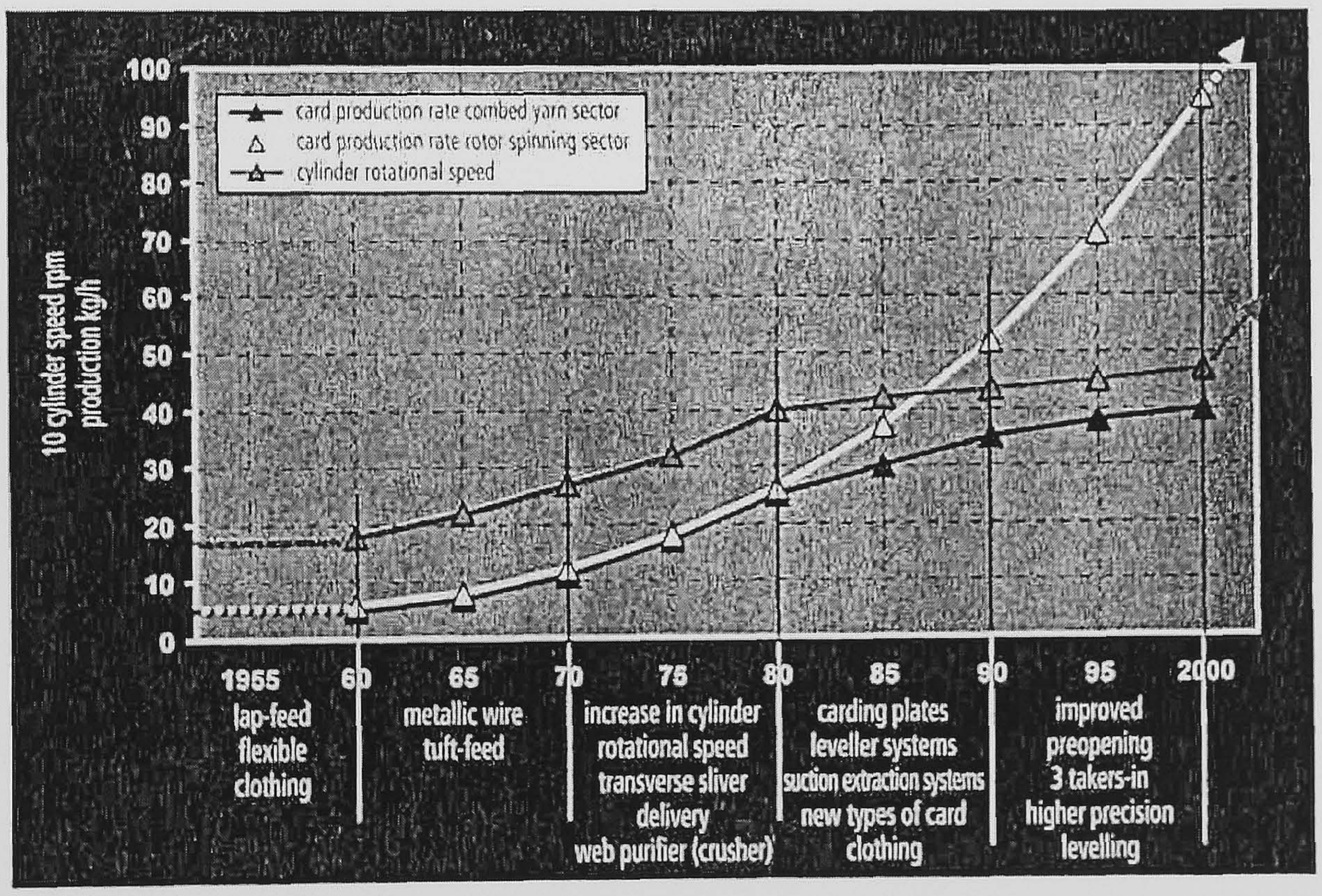

Figure 1.13: Developments in Carding and Production rate increases [24]

One significant prerequisite for today's high productivity has been the demise of flexible-wire card clothing since 1960 [24]. While it is true that the card design has evolved over the years and has contributed immensely to the productivity of the cards, it is important to mention that the development of card clothing has similarly evolved over the years.

Modern high production carding machines offer a number of features:

1. Two piece chutes with an integrated opening roller for ensuring an open and even feeding to the card and also in some cases the elimination of the transfer table, for example Truetzschler DK 803/ 903 [25].
2. Greater cylinder speeds of up to 600 rpm for a 50 inch cylinder and up to 900 rpm for a 40 inch cylinder [26].
3. Single or triple taker-in arrangements.
4. Pre-opening and cleaning arrangements with continuous suction of released foreign matter and short fibres in the licker-in zone and on the cylinder, before the main carding zone.
5. Flats that can be driven in either direction: clockwise or counter-clockwise.
6. Post carding stationary flats with cleaning arrangements for ensuring fibre individualisation and parallelisation before transfer to doffer.
7. New web doffing arrangements that ensure proper condensation of the web into a sliver at high sliver speeds of up to 300 metres per minute.
8. Large diameter cans of up to 1000 mm and automatic can change.
9. Fully enclosed cards with efficient suctioning arrangements at all dust release points to ensure low dust levels in the carding environment.
10. Addition of a draw-frame at the delivery of the card, which is claimed to minimise one passage of drawing (instead of two passages used normally) especially for rotor spinning.
11. Electronic aids are replacing manual setting of the machine for greater accuracy.

To achieve higher speeds and productivity rates, the engineering aspects of the card design have undergone extensive changes. Precision engineering has made it possible to achieve extremely close settings, low vibration and noise levels, and reduced card maintenance and care requirements. All the rotating elements run on anti-friction bearings and are dynamically balanced to ensure smooth running at high-speeds. Timing belts, instead of gear wheels, are used in many drives to reduce the noise levels, reduce maintenance and wear and tear. The cylinder, the core of the card, is made with steel and is balanced accurately to a few grams of residual imbalance [27]. The doffer is driven using a separate motor and the speed of the doffer can be programmed to accelerate gradually to the actual set delivery speed in order to reduce sliver breaks.

The cross-section of Rieter C 60 card shown in figure 14 incorporates most of the features mentioned above.

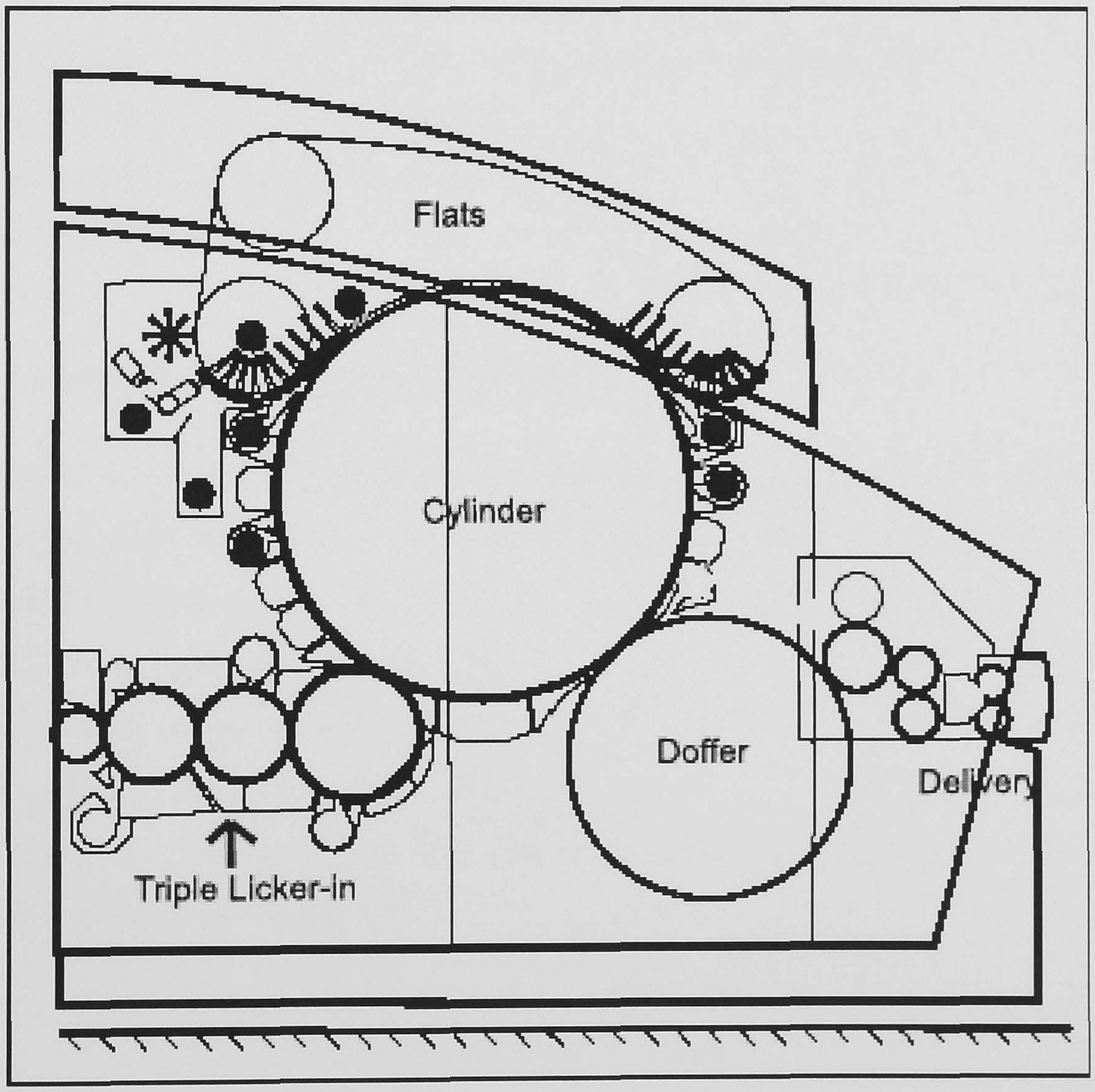

Figure 1.14: Rieter C60 card [26]

1.4 Studies on the pre-opening function of the licker-in zone of a Single Licker-in system

1.4.1 Fibre processing at the feed roller nip

Fibre processing at the feed roller nip is influenced by the following factors.

1. the geometry of the fibre intake zone.
2. the speed of the licker-in
3. homogeneity and parameters of the fibre mass at the feed.
4. the licker-in wire specifications
5. setting of the feed plate to the licker-in and
6. the lap feeding rate

1.4.1.1 Geometry of the fibre intake zone

The work of the licker-in is essentially determined by the geometry of the intake zone. Figure 1.15 shows the arrangement of the feed roller and the licker-in, which takes off the fibres from the feed lap. The accuracy of the nip decides the effectiveness of the opening. The length of the feed nose combines with fibre friction to determine the fibre cohesion that must be overcome if a fibre is to be combed out of a fibre tuft. The position of the fibres in the lap and the position where they are contacted by the licker-in tooth play an important role in determining the fibre stress. [3].

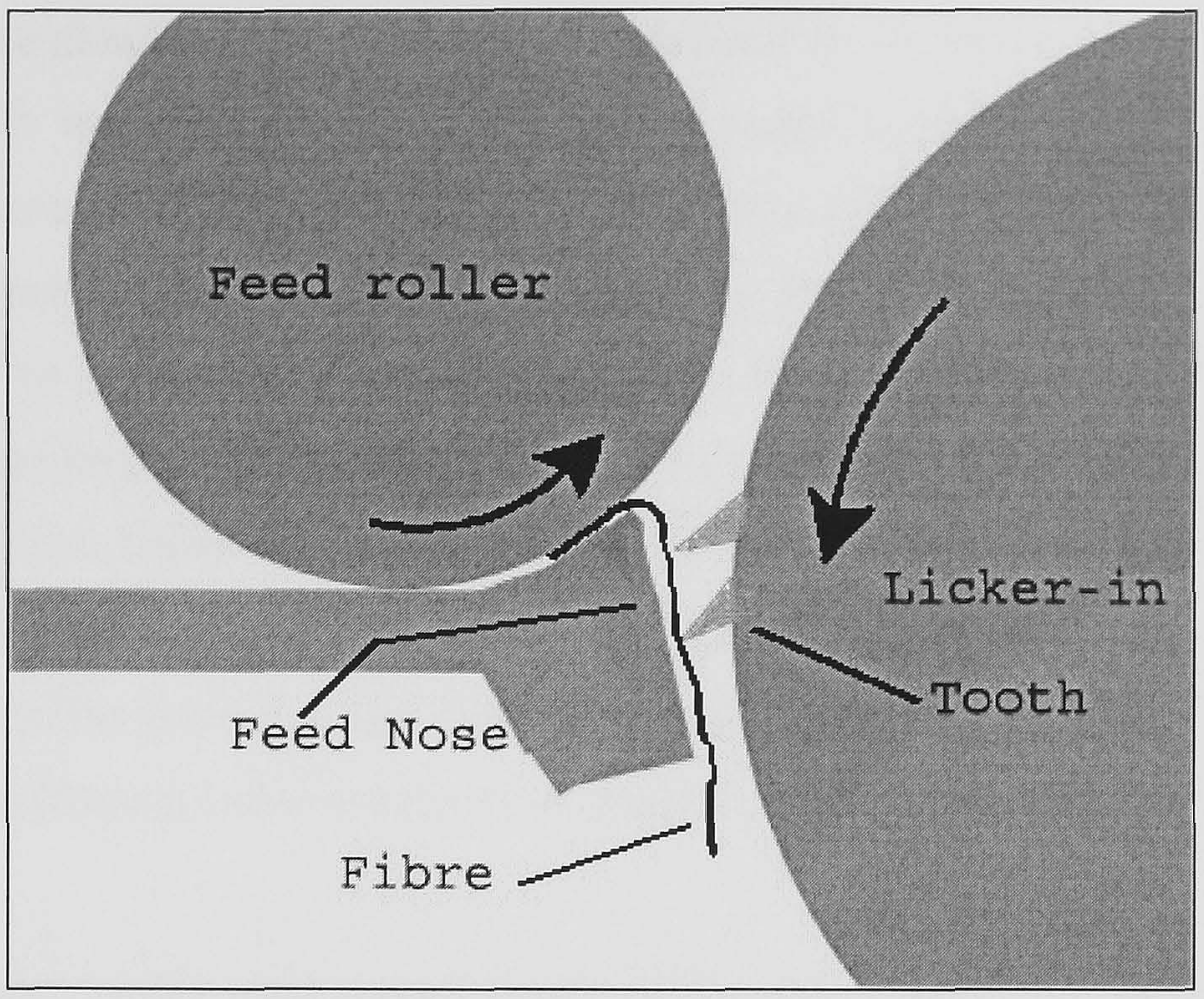

Figure 1.15: Action at the feed-nip

Since the lap bends sharply near the point where it is gripped, there is also a layer-by-layer difference in the combing action of licker-in wires. In their observation of the front end of a lap taken out by the reverse motion of the feed roller after its stoppage, Niitsu *et al* [28] found that the respective lengths of the fibres combed by the licker-in wire are shorter in the lower layers than in the upper to the extent that the fibres in the lower layers of the lap are hardly combed by the licker-in wire.

1.4.1.2 Speed of the licker-in

At the feed roller nip, the fibre is subjected to severe stress, as the fibres are strongly nipped and rapidly accelerated to the licker-in speed, where the surface speed is in excess of 10 m/s. As the feed rate is very small compared with the licker-in speed, fibres are easily torn or formed in to flocks.

In one study [29], it was observed that at low licker-in speeds, a strong accumulation of fibre flocks occurred on the cylinder surface, before the fibres entered the revolving flats and the fibre covering on the cylinder surface was inhomogeneous. Also, the region of the greatest change in flock count was found to lie between the slowest (670 rpm) and the nominal licker-in speed (800 rpm) for the cotton used. It was also observed that at nominal licker-in speeds, the cylinder covering was complete and uniform with good fibre orientation in the carding zone. About the same level of opening progress was found by increasing the licker-in speed further to a very high speed (1600 rpm). At very high licker-in speeds (1600 rpm) no further improvement of the homogeneity in cylinder covering was found. It was observed that there was a shifting of characteristic flock size towards smaller flock sizes at greater licker-in speeds. The above study showed that there is no linear relationship between the licker-in speed and the pre-opening results and also that the optimum licker-in speed is independent of the production rate.

1.4.1.3 Homogeneity and parameters of the fibre mass at the feed

The degree of processing depends not only on the geometry of the nip zone, but especially on the homogeneity of the compressed fibre mass along this nip zone at right angles to the direction of feed [3].

The non-homogeneity of the lap results from the scattered orientation of fibres in the mass and the combination of these fibres in flocks of dissimilar geometry, size and density. The orientation of fibres within each of the cotton tuft is fairly good (the fibres were better oriented within the tuft), but the orientation of the fibres between adjacent cotton tufts in the lap is bad that it was reported to be between 0.51 and 0.57 in one study [28].

Lap compression results in a fibre retentive force that must be overcome if a fibre is to be removed from the lap. When the point is reached where fibre cohesion is smaller than the friction between the fibre and the licker-in clothing, the fibre is combed out and moved off by the teeth of the licker-in [3]. Therefore, the greater the compression, the greater will be the licker-in moment.

The moment generated in the licker-in due to the opening of the fibre mass could be taken as a measure of fibre stress, the moment being proportional to the opening force and this provides an objective measure of fibre stress in the preliminary opening zone [3]. The licker-in moment could be affected by two parameters viz. lap gauge and delivery speed (i.e. feed rate). Thick laps increase the friction in the lap and the fibre cohesion due to compression and it was found [3] that the relationship between the opening force and the lap weight was not linear. In the same study, it was also found that for preliminary opening, the fibre presentation weight must not be too high in order to save the length distribution and that it is better to process lower lap weights at higher feed rates than the other way round. Also, licker-in speeds greater than 900 rpm was found to result in greater reduction in mean length, especially for higher feed weights.

1.4.1.4 Setting of the feed plate to the licker-in

The position of the fibre in the lap and the point where the fibres are contacted by the clothing have an important influence on fibre stress and hence fibre shortening. The closer to the nip line the tooth grasps the fibre, the greater is the force of acceleration. The danger of fibre shortening increases markedly when the fibre lies diagonally and when the tooth picks up the fibre close to its nip point [3].

In their work, Niitsu *et al* [28] analysed the size distribution of cotton fibre tufts on the surface of the licker-in. It was found that as the setting between the feed plate nose and licker-in was increased, the number of larger size tufts increased (twice as much as with normal setting). While the trash removed by the licker-in decreased considerably, the impurities and the neps in the sliver increased significantly.

1.4.1.5 Licker-in wire specifications

The friction of the fibres against the clothing of the licker-in is an important parameter that influences the pre-opening process and this friction is influenced by the tooth configuration and number of teeth per unit area. When the tooth angle of the licker-in wire was increased, the number of small and medium tufts increased [28]. This was attributed to the weakening of the fibre holding force of the teeth and their reduced combing capacity. Also the trash removed under the licker-in decreased.

1.4.1.6 Feeding rate

The low speed of feeding to the licker-in leads to a milling effect and if the tooth engages crosswise with fibre that is nipped at both ends, then the fibre may be torn if fibre cohesion exceeds the fibre tearing strength. It was observed [3] that if the lap weight remains the same and the feed rate is altered, the licker-in moment changes in linear proportion with feed rate and this was attributed to the frictional and cohesive forces within the lap that hardly changed.

It was found [29] that at a nominal licker-in speed, the lowest feed rate showed only individual fibres with a high degree of orientation on the cylinder surface. When the feed rate was increased to moderate levels, the fibre cover on the cylinder became much less homogeneous, revealing fibre accumulations that still showed orientation and at the highest feed rate, almost the entire clothing was covered with the fibre mass. It was observed that the feed rate had only a small effect on pre-opening and therefore, correct licker-in speed can provide good pre-opening, even at high production rates.

The number of cotton fibre tufts increased with an increase in lap-feeding rate or with a decrease in the licker-in speed and vice versa [28]. It was also observed that the impurities and the neps increased in the sliver significantly as the lap-feeding rate increased. This is primarily because the flats get clogged up with tufts quite rapidly and thus the carding action between cylinder and flats becomes less effective leading to more faults in sliver.

1.5 Multiple Licker-in Designs

A critical review of the different licker-in designs provides an understanding of the key requirements of a successful licker-in design.

From the review, it was apparent that there are over fifteen licker-in arrangement designs, of which only a few were translated to the market place and only one has found commercial acceptance, apart from the existing single licker-in arrangement. Those designs, which were incorporated in to commercial models and those (from patents) that might be interesting from a technological point of view, are discussed.

1.5.1 Limitations of Single Licker-in design

Single licker-in design has been discussed in detail in section 1.3.2.2 and the following is the discussion on the limitations that led to the development of new designs.

The licker-in carries out 90% of the cleaning work of the total cleaning done by the card [27]. Figure 1.5 (page 8) shows a modern taker-in arrangement used in Truetzschler cards. The throughput through the single licker-in has increased several times since the 1950s; however, its speed has not increased by the same proportion. It was around 400 rpm with a production rate of 4 kg per hr and presently it is 800 – 1200 rpm in most cases [6]. This means that the opening achievable at the feed nip of the feed plate is considerably reduced. Therefore, without any modifications, the licker-in would deliver mostly flocks, to the main cylinder. These tufts are compact and relatively poorly distributed across the surface of the licker-in and would result in considerable loading of the cylinder and flats clothing [6]. A large flock is carded with the same relative speed as a smaller flock in the cylinder-flat region. This ought to result in greater stress on the carding elements and on the fibres when the large flocks are being carded. The danger of fibre shortening also increases [3]. Waste from the flats was also observed to increase if the fibres from the licker-in had more tufts [30].

Therefore, modern cards employ other means to ensure that the tufts are properly opened, cleaned and distributed before they enter the main carding zone (cylinder/flats). This led to the introduction of stationary opening segments (one or two) under the licker-in and stationary opening segments, which were introduced in the region before the main carding zone, on the cylinder so that the card production could be increased [6].

It was possible to achieve increases in the productivity of the card by increasing the number of licker-ins. Several attempts were made to redesign the licker-in zone to use multiple lickers-in and today two commercial models of card with multiple licker-in arrangements are available. These arrangements will be discussed in the following section (1.5.2).

1.5.2 Multiple licker-in designs

The Russians were among the earliest to recognise the limitations of a single licker-in arrangement. In the literature published in the 1960s, reference is made to 3 designs by Russian machinery manufacturers [31-33] viz:

1. Single licker-in arrangement with one set of worker and clearer rollers as shown in figure 1.16.
2. Single licker-in arrangement with two sets of workers and clearer rollers as shown in figure 1.17.
3. Two lickers-in with the second licker-in having two sets of worker and clearer rollers as shown in figure 1.18.

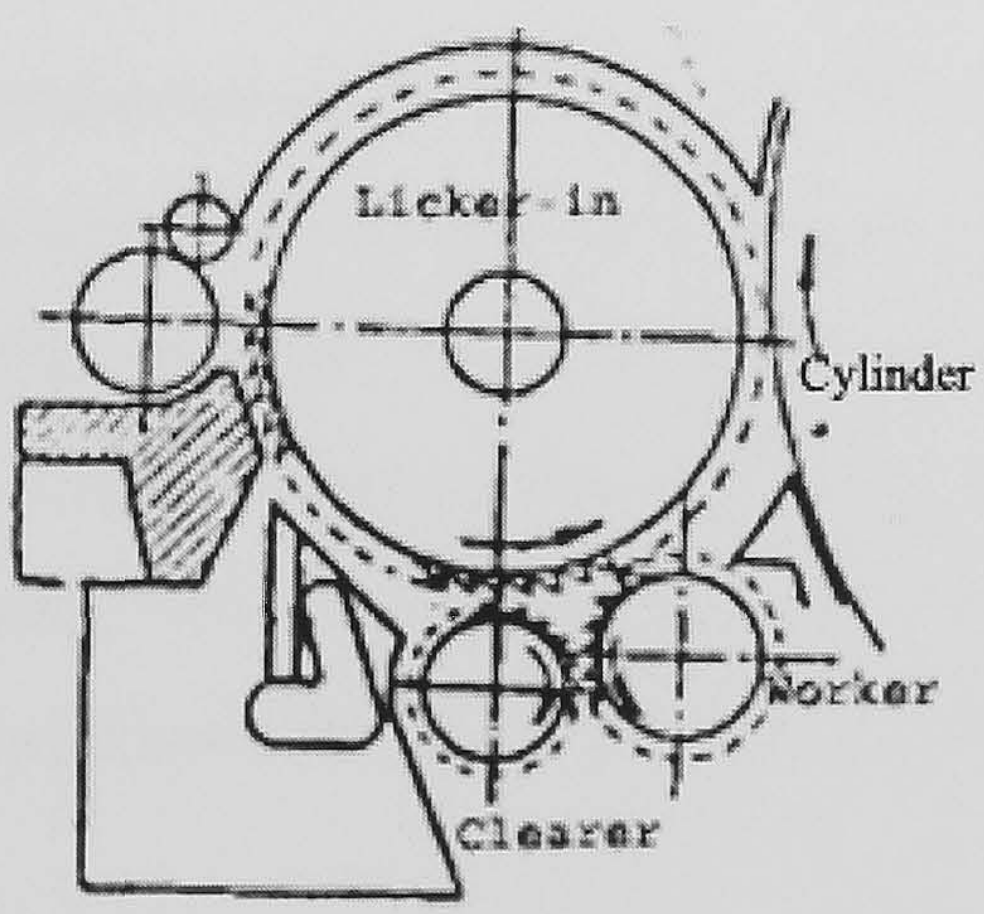

Figure 1.16: Licker-in with one worker and one stripper

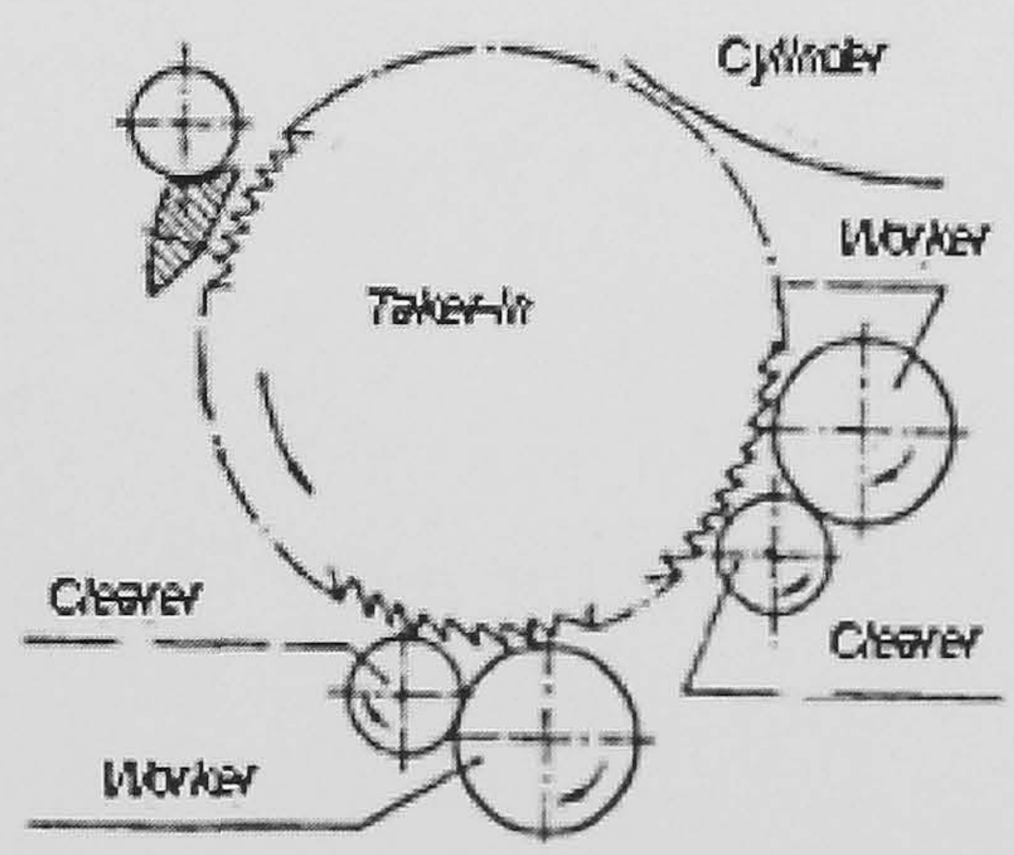

Figure 1.17: Licker-in with two sets of workers and strippers

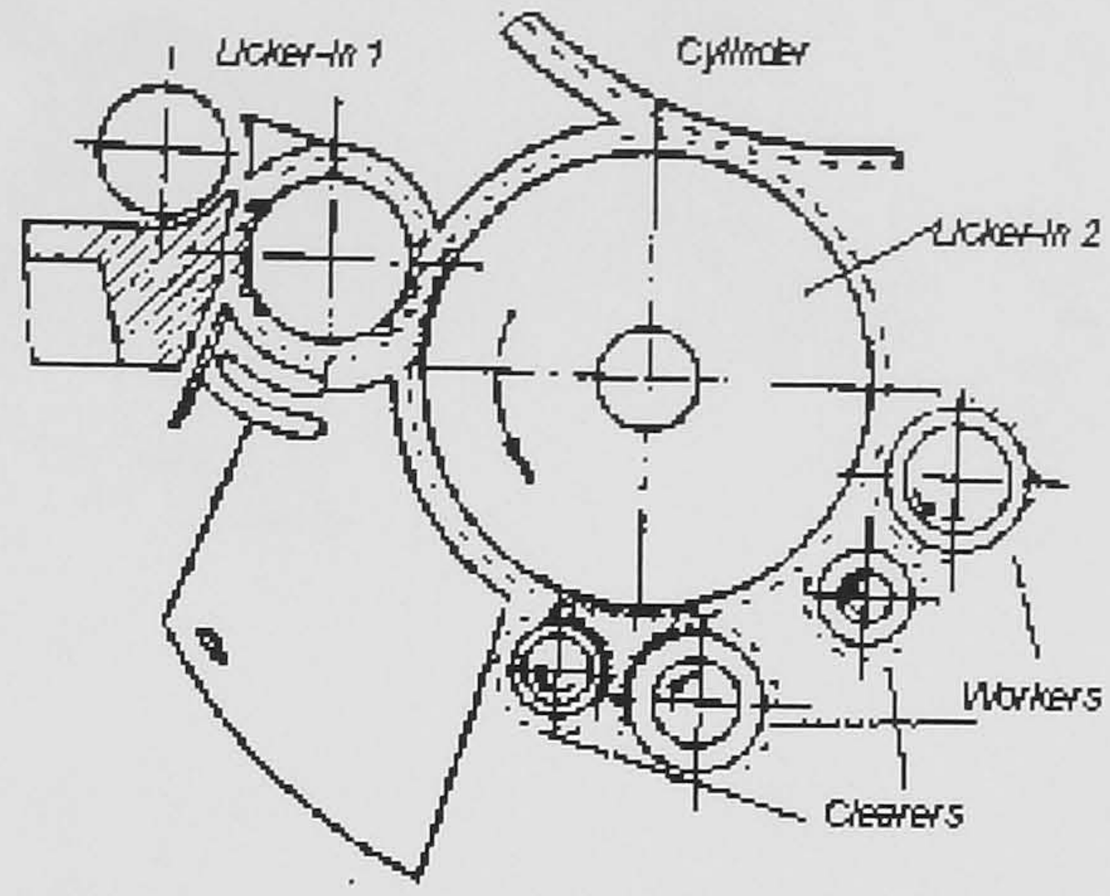

Figure 1.18: Two Lickers-in arrangement

None of the above designs by Russian machinery manufacturers penetrated the world market. The only probable reason for this could be that these designs did not meet the expected quality and/or productivity levels of carding. Several licker-in designs were also patented in Europe and a few of these designs were introduced commercially. They can be conveniently classified as double licker-in designs and triple licker-in designs.

1.5.2.1 Double licker-in designs

A double licker-in design, introduced by Schubert and Salzer in 1975, was a major advancement in licker-in design (Figure 1.19). The standard licker-in was replaced by the combination of two lickers-in, of which the top licker-in ran at more than twice the speed of the lower licker-in [5]. Their arrangement was such that they were in the carding position with respect to each other [1]. Schubert and Salzer claimed that the lower licker-in prevents large tufts from reaching the cylinder and as a result, the cylinder surface would be covered with well opened, evenly distributed fibres for best carding conditions.

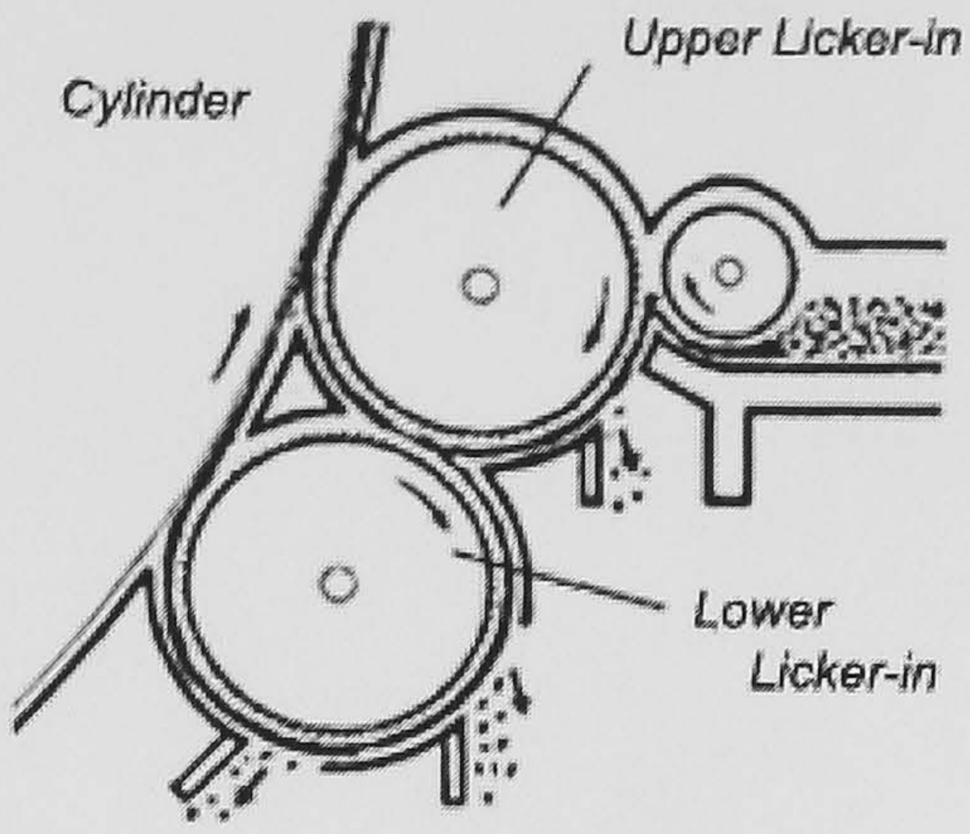

Figure 1.19: Double Licker-in system of Schubert and Salzer

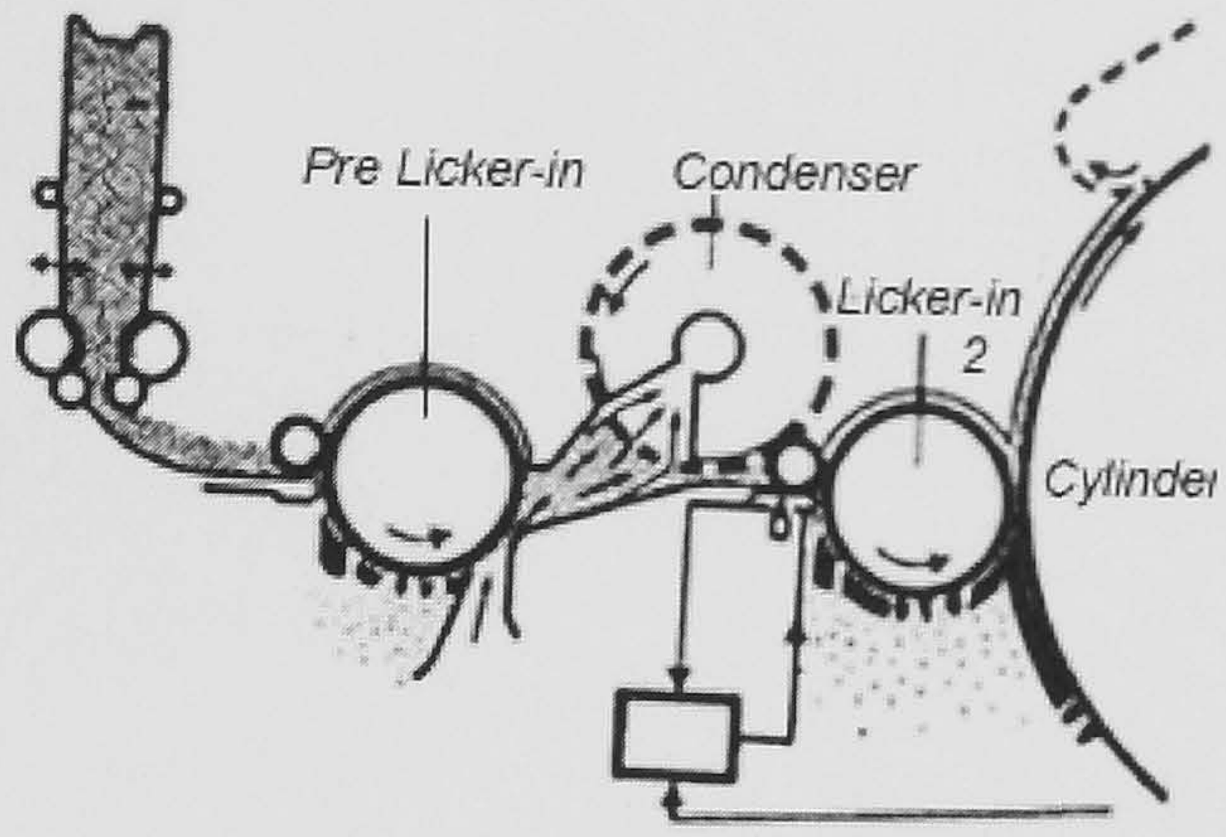

Figure 1.20: Double Licker-in system of SACM

The other interesting licker-in design of the 1970s was the SACM's HP7 high production card, which used two lickers-in shown in figure 1.20. The pre-licker-in delivered the opened tufts onto the surface of a condenser for dust removal. The matt formed on the surface of the condenser was peeled off by a feed roller and forwarded to the second licker-in for additional opening and cleaning, before it passed on to the surface of the cylinder. Each licker-in had a mote knife and a screen with grid bars [5].

1.5.2.2 Triple licker-in designs

Schubert and Salzer brought out a triple licker-in arrangement in 1978, in the form of the Supercard KU 12 shown in figure 1.21. It was claimed that by arranging three opening rollers in succession with increasing circumferential speed, the following requirements were met:

- low circumferential speed on the first opening roller for a gentle fibre take-off from the feed roller and

- an effective cleaning system around the 3 opener rollers to ensure extraction of all coarse impurities from the feed batting [34].

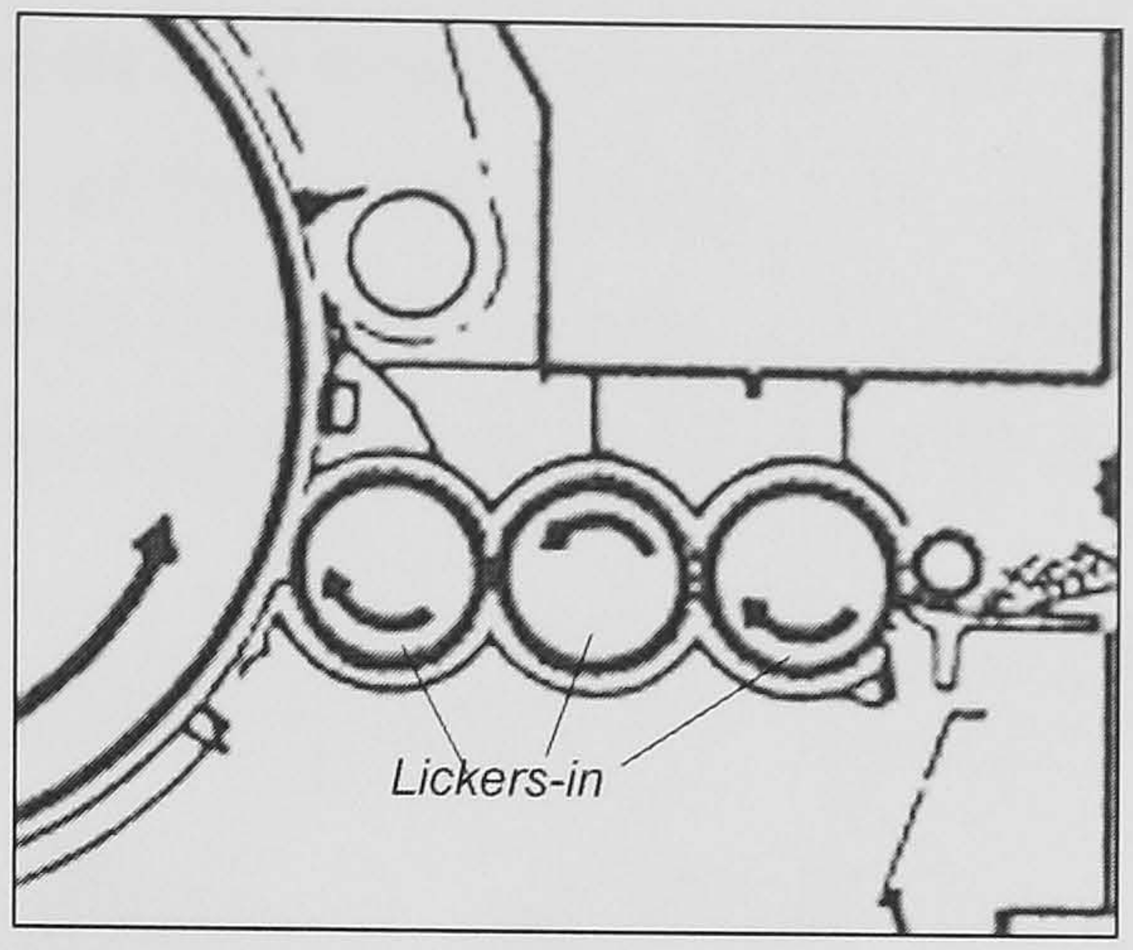

Figure 1.21: Schubert Salzer's Triple Licker-in Design

In 1995, Truetzschler introduced a redesigned triple licker-in arrangement for their DK 803 card, claiming that the previous triple licker-in designs gave more importance to cleaning than opening. The new arrangement was designed to give equal importance to both opening and cleaning, and ensured that a web of fibres was fed to the cylinder [2].

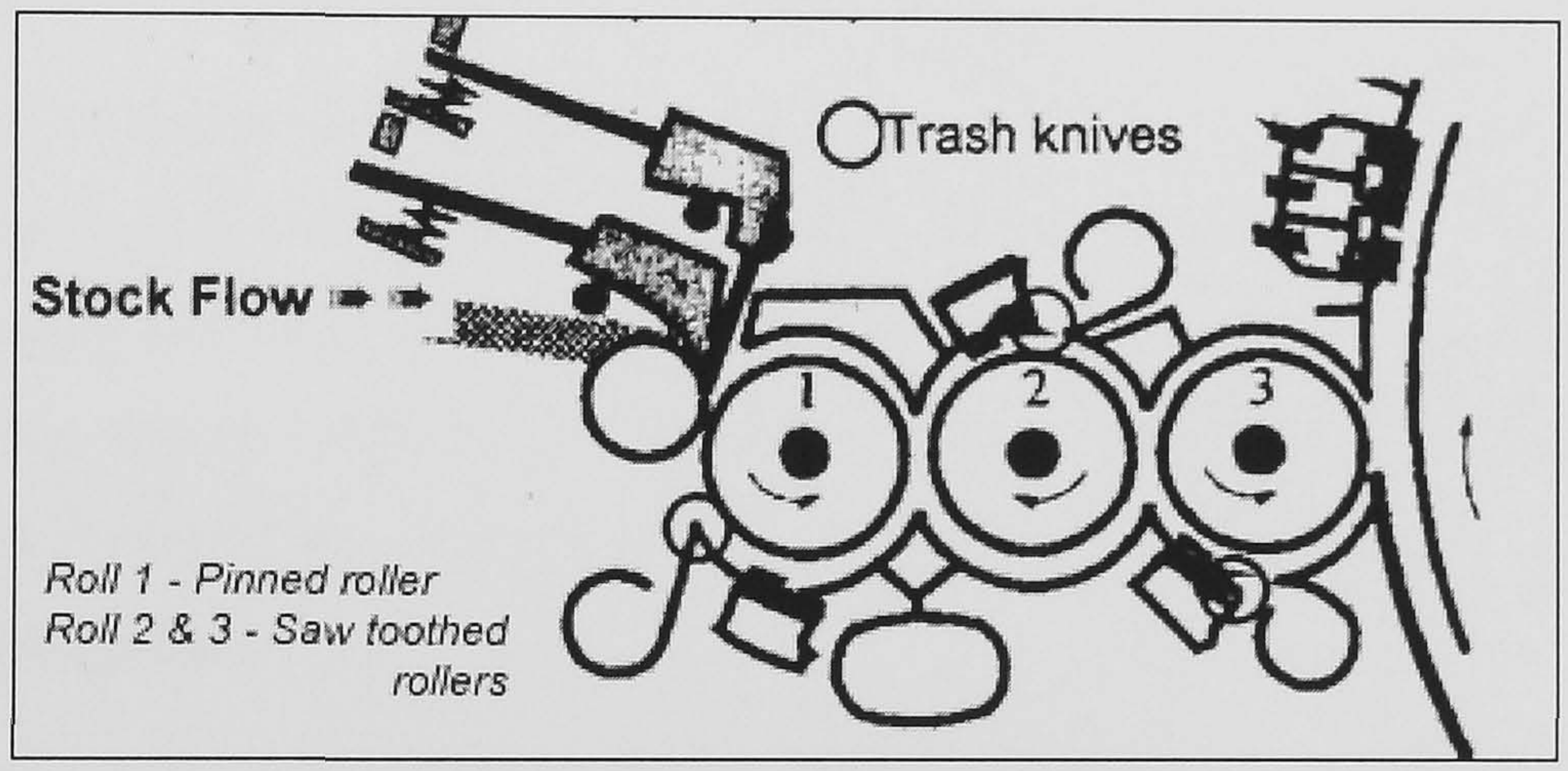

Figure 1.22: DK 803 triple licker-in design

The DK 803 card has three lickers-in arranged in series with the first roller spiked to provide a gentle opening (Figure 1.22). The other two rollers have progressively finer clothing and are run at progressively higher speeds resulting in a stripping action. This arrangement is said to permit finer wires and higher speeds for the cylinder, without the associated disadvantages like fibre breakage or wear of the cylinder/flats clothing [2].

In 2002, Rieter launched its own version of a triple licker-in design namely the C60 card. The main feature of this arrangement is the use of two small licker-ins followed by a large licker-in (Figure 1.23). Not much information is available about the performance of this arrangement, as it has just been released commercially.

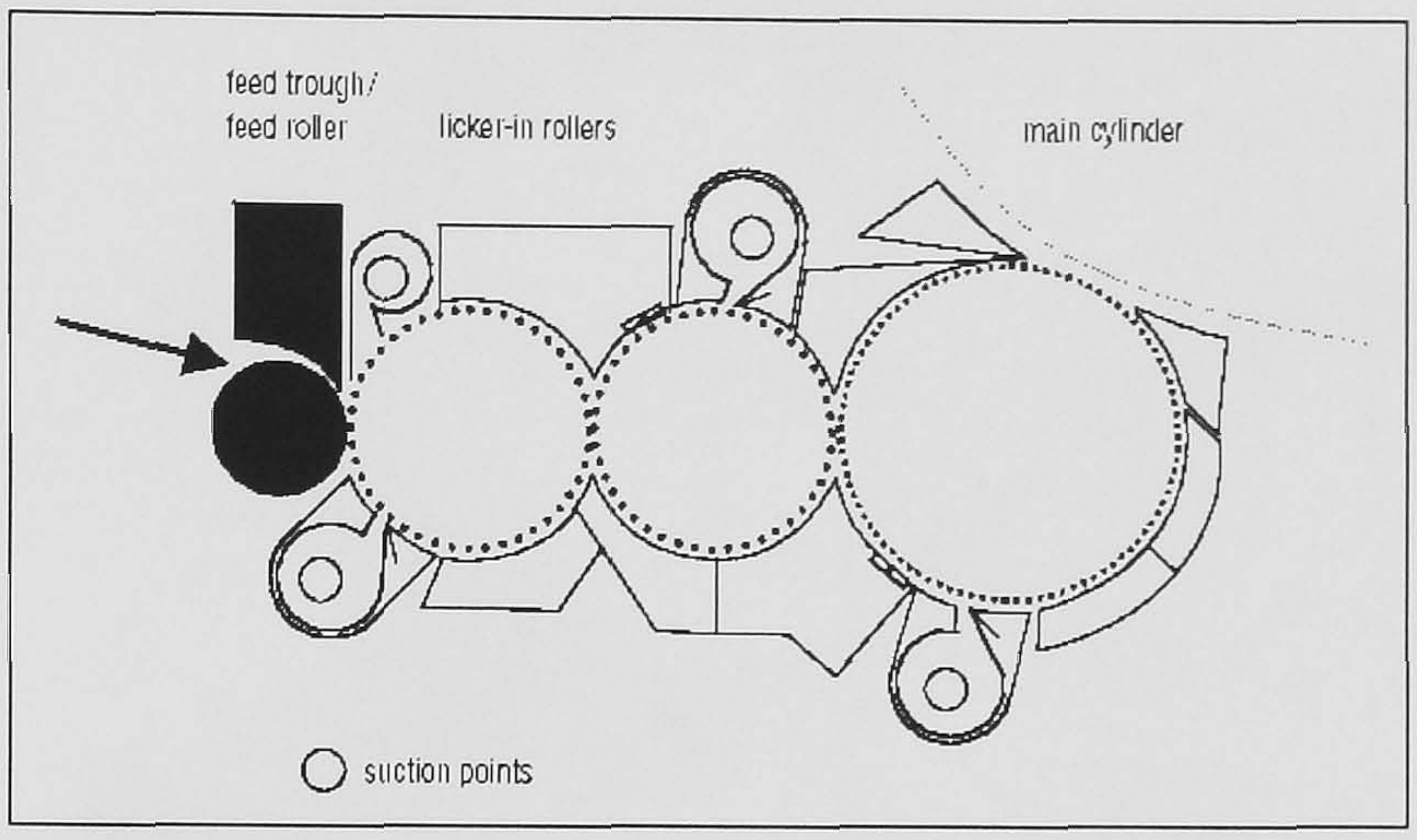

Figure 1.23 - Rieter's triple licker-in design

1.5.3 Designs from patent literature

US Patent 4 355439 [35] details the design of a triple licker-in arrangement, as shown in figure 1.24. The device has a cylindrical drum, with a large diameter, which is placed between the first and third lickers-in. A series of stationary flats with cleaning knives encompass the cylindrical drum, which leads to greater opening and cleaning at this zone. The design is said to efficiently clean cotton, wool and waste fibres.

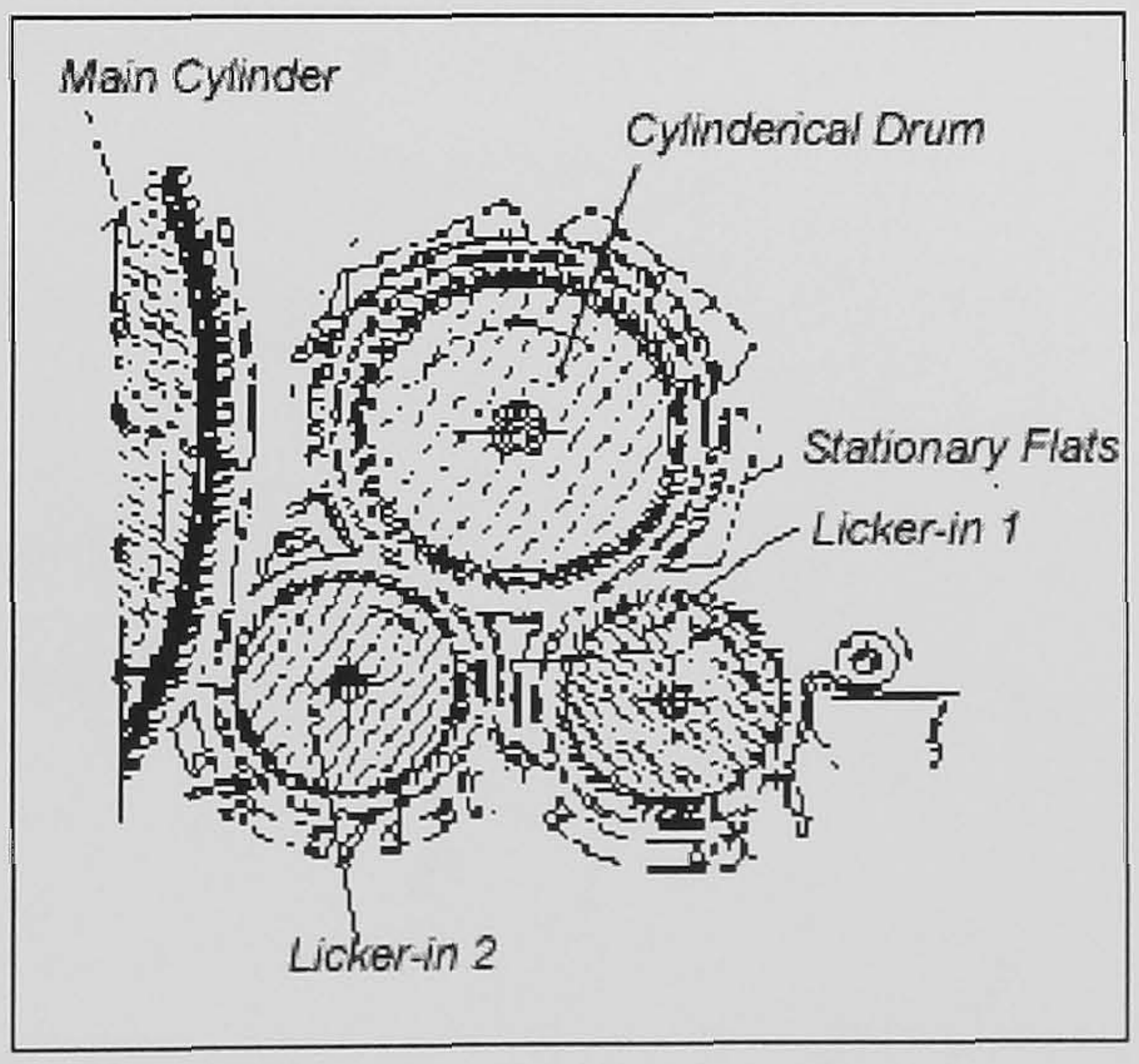

Figure 1.24 - Patent of Juan Estebanell

UK patent 2 247 253A [36] details the design of a licker-in arrangement awarded to Truetzschler GMBH in 1992 (figure 1.25).

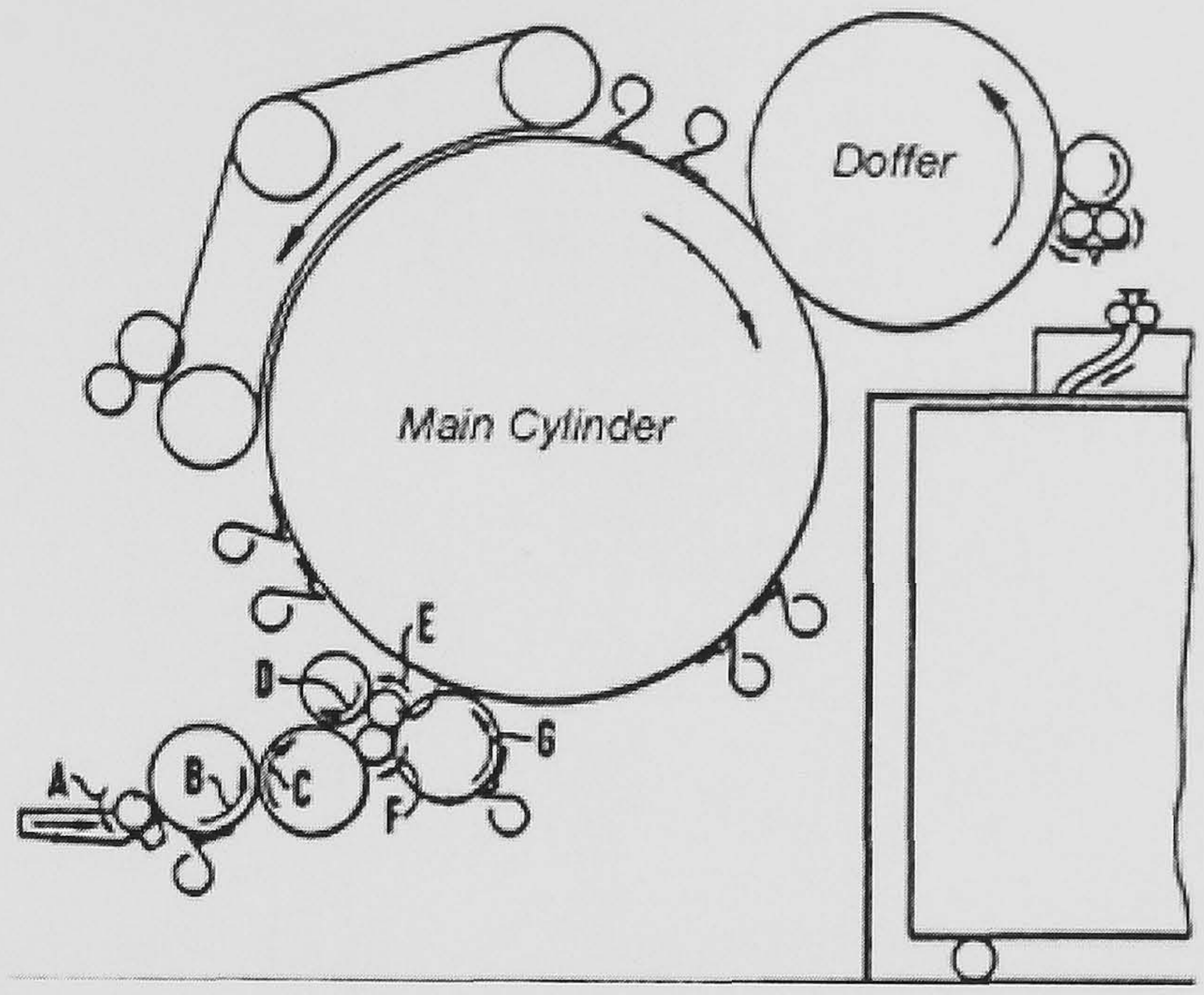

Figure 1.25 - Patent of Truetzschler

A doffer roller(C) and a stripper roller (D) are arranged between the licker-in (B), a pair of rollers termed press rollers (E) and the main cylinder. The stripper roller (D) introduces the fibre material from the doffer roller, to the nip of these press rollers. The press rollers feed the material to the transfer roller (F), which feeds to the main cylinder. The function of the press rollers is to crush foreign components in the fibres so that they fall out as the material is carried further. Truetzschler claims that this arrangement is suitable for the removal of neps, which have very small remnants of husks in the core with fibres adhering to them, and are known to be difficult to remove during carding.

International Patent Publication No: WO 92/ 16676 [37] awarded to Andre Varga of Crosrol in 1992 is shown in figure 1.26.

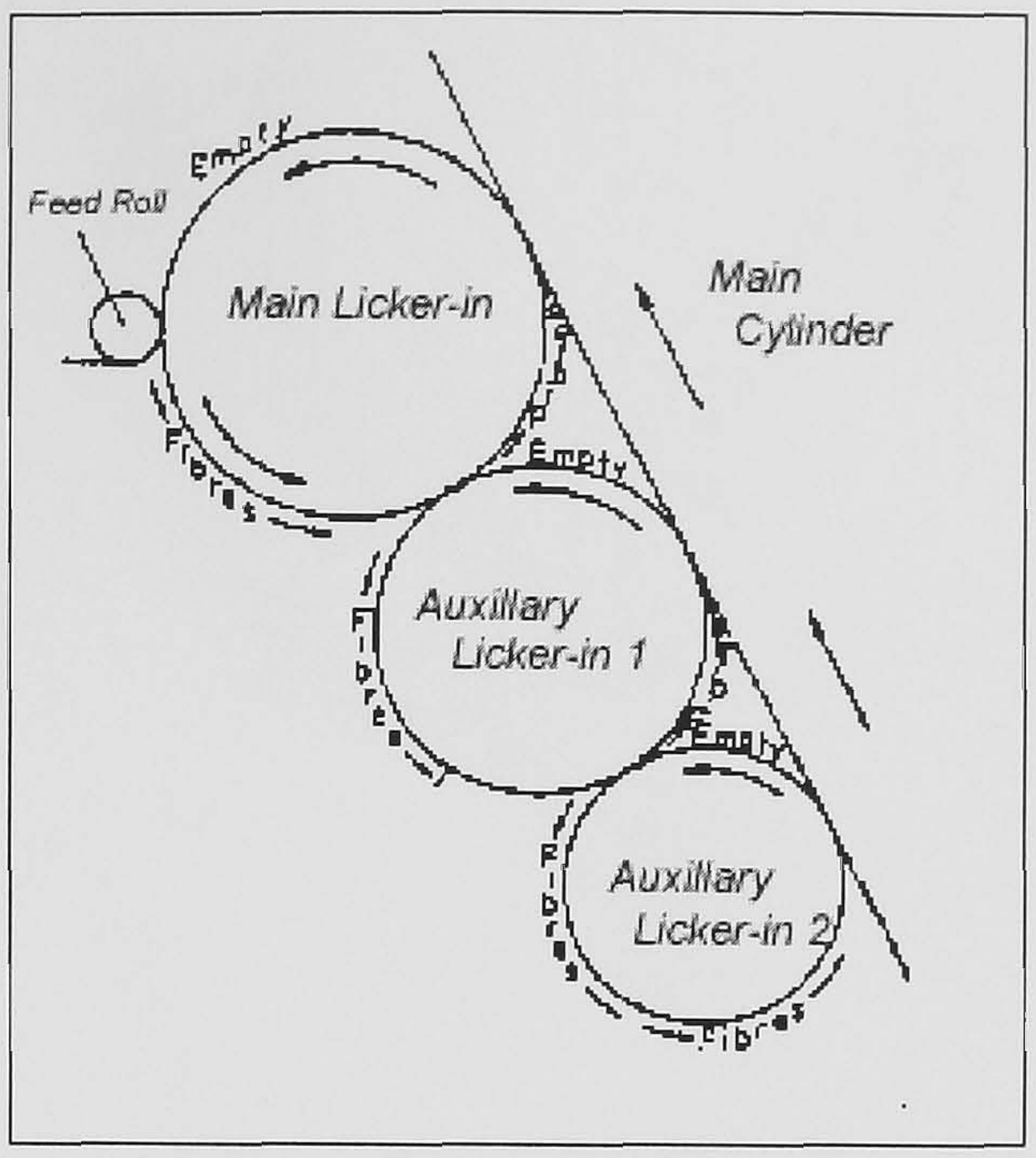

Figure 1.26: Patent of Crosrol

In this arrangement, there are two auxiliary licker-in rollers in the opening zone. The first auxiliary licker-in has a working function with the main licker-in roller, rotating in the same direction in order to disentangle any large fibre tuft or agglomeration on the main licker-in. The additional auxiliary licker-in also works like the first, having a working function with the first and being in stripping disposition with the main cylinder. Preliminary experiments suggested that the design substantially reduced the yarn neppiness.

In 2000, US Patent No: 6 061 878 [38] was awarded to Marzoli for their design shown in Figure 1.27.

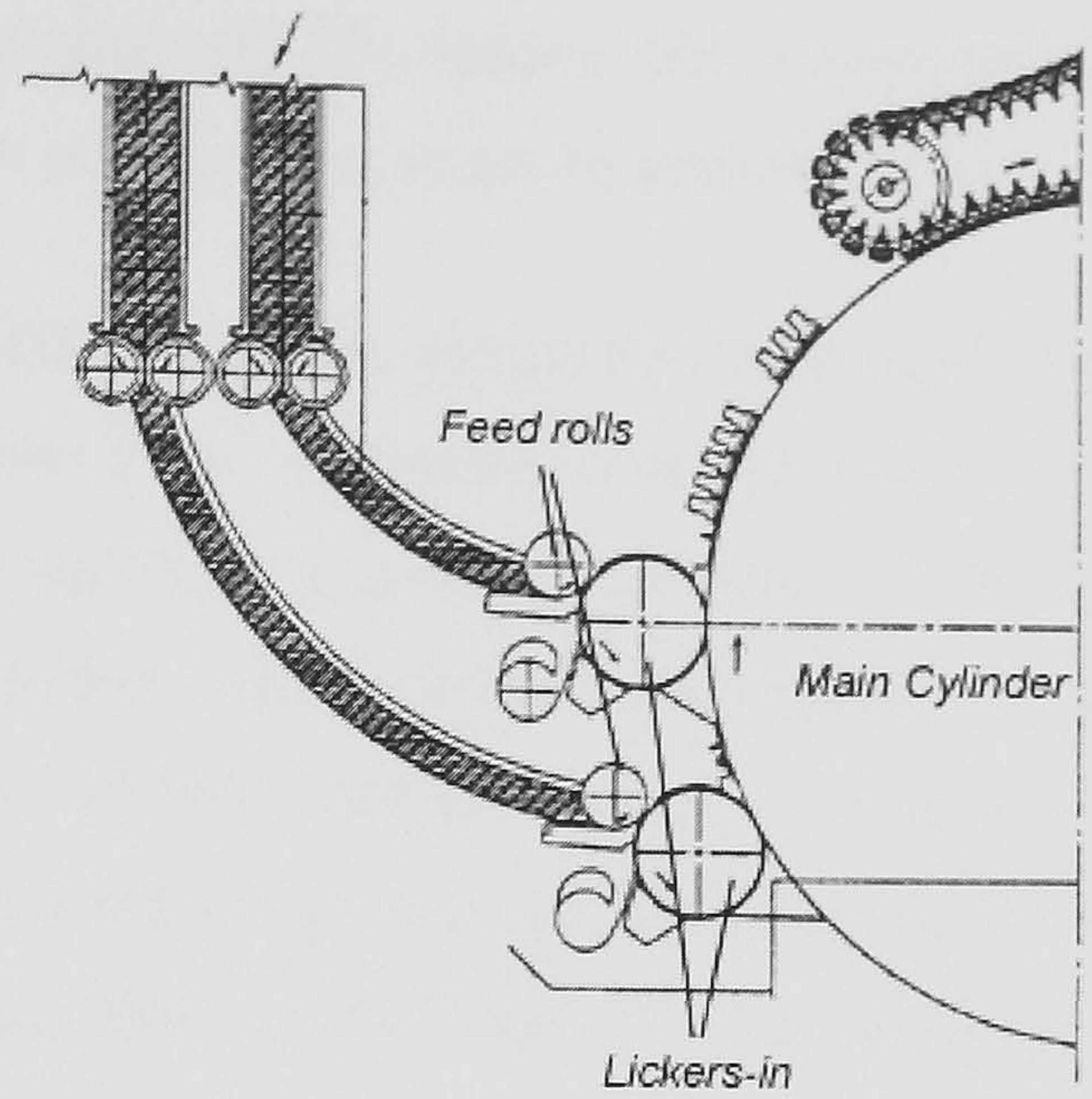

Figure 1.27: Patent of Marzoli

In this arrangement, the licker-in zone has multiple lickers-in, all feeding simultaneously to the main cylinder. Each licker-in is individually fed by a feed roller/ feed plate arrangement. Therefore at a given production rate, in a licker-in zone with two concurrent lickers-in, the amount of material handled by each will be halved and it is claimed that this results in improved opening and thus a better purity and uniformity of the carding sliver in comparison with a normal single licker-in arrangement.

1.5.4 Licker-in designs – A critical review

The limitations of the single licker-in with respect to pre-opening have been discussed in detail earlier, however an overview will be given here. Card production has increased steadily since the 1950s from 4 kg to up to 100 kg per hour. Clearly, the licker-in elements of modern cards are required to handle large quantities of fibre per unit time. However, this is at the risk of increased fibre damage as the licker-in speed exceeds its optimum [1]. After a detailed study of the various aspects relating to the licker-in zone, Artzt and Schreiber [3, 29] concluded that increasing the licker-in speed is not a viable means for improving the quality of pre-opening and that when large fibre masses are processed, the pre-opening element must be re-configured. To reduce the stress on individual fibres, every opportunity to improve pre-opening must be exploited [24].

Fibre stress and card clothing wear are interrelated and from the wear of the pre-carding segments, it could be concluded that the carding at this zone is still on going. In addition, an increase in production rate results in short term and local overloading of the cylinder, which put an unacceptable amount of stress on the fibres [39]. Dehghani *et al* [40] studied the flow variation of tufts and fibres on a modern single licker-in card using state of the art high-speed photography. It was found that the fibre mass flow at the licker-in output still contained a large number of tuftlets and fibre clusters. The fibre mass flow was seen to have improved, with a more open and uniform distribution of the fibre mass only on the cylinder, immediately after the stationary flats on the rear of the card, indicating the importance of pre-opening elements prior to the main carding zone. When the licker-in speed was increased from 670 rpm to 1600 rpm, the carding force at the first flat decreased by 30% [41]. However, it was found that increasing the licker-in speed without a corresponding increase in cylinder speed, while reducing the fibre orientation on the back of the cylinder, also reduced the number of carding neps [42]. It is evident that the carding efficiency can be improved either by improving the preliminary opening, leading to a decrease in the load on the actual carding zone, or by making improvements in the main carding zone i.e., where there is an interaction between the cylinder and the flats. It was observed that in tandem carding, the carding force drops to 50% of its single carding value [43]; this illustrates the need for good pre-opening. Needless to say, achieving a higher fibre throughput whilst maintaining the same quality is only possible by increasing the efficiency of the carding action[1].

The intensity of the carding is influenced to a considerable extent by the use of additional carding rollers [44] . Artzt *et al* [1], state that with the arrangement of two lickers-in running in opposite directions (see figure 1.19, page 30), there is no guarantee that the fibres pass easily from first licker-in to second licker-in and the fibre flocks can revolve uncontrolled on the first licker-in. However, the argument about fibre flocks revolving uncontrolled on the first licker-in is not clear as the

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first licker-in also transfers the fibres to the cylinder, just as a normal lickers-in would.

According to Artzt *et al* [1], an arrangement of three lickers-in must be used to ensure a homogeneous flow of fibres. Feil [14] comments that with three lickers-in having carding plates, the opening capacity of the fibre intake system increases by a factor of 4 or 5. In their experiments with the three lickers-in arrangement, Artzt *et al* [1] claim that there is no damage to the fibre as the speed of the first licker-in is relatively low. The triple licker-in arrangement was found to produce a uniform yarn with fewer thick places and better strength, even with higher sliver weights, than the double licker-in arrangement. Interestingly, the number of thin and thick places in the yarn increased with the triple licker-in arrangement when carding segments were introduced. These conclusions seem to be at variance with the arguments for the new triple licker-in design of Truetzschler, which has opening segments. Gilhaus [45] reported that trials with a Supercard KU 12 having a triple licker-in arrangement showed significant improvements in quality for both cotton carded and combed yarn counts. Yarns were better in strength and exhibited reduced Classimat faults with a simultaneous reduction in comber noil by 3 to 5 %, this is said to be due to a reduced number of short fibres and an improved parallelisation of fibres in the card sliver.

In a more recent work, Rimmer [46] found that although carded ring yarns produced on a triple licker-in system were more even than those produced on a single licker-in, the fabrics produced from these yarns were trashier, more irregular and prone to pilling than the single or tandem carded yarns. She also claimed that the fibres, in both ring and rotor spun yarns produced from the triple licker-in slivers, exhibited a fine crimpy effect with an increased number of hooked and looped fibres and a high number of fibre sections protruding from the body of the yarns compared to single or tandem cards. The industrial anecdotal evidence also indicates that the new design is not very successful with finer micronaire cottons.

Mills [47] states that theoretically, with the triple licker-in operating under optimum conditions of roller speed and clothing point population, fibre individualisation is achieved at the intermediate licker-in roller as the average number of fibres per tooth is reduced to less than 1. She further states that as the individual fibres are at this stage not properly parallelised, their fibre extents are reduced. Also with the restraining effect of fibre/fibre friction substantially lost, a high proportion of the fibres presented to the cylinder are oriented transversely to the direction of flow, leading to the generation of fibre neps and to impairment of the combing action between the cylinder and the flats. However, the main argument against excessive individualisation seems to be only based on the number of teeth per fibre available at the intermediate roller and not on the actual opening action achieved at this roller. An intensive opening action between two co-operating surfaces having sufficiently greater population (like cylinder and flats in the main carding zone) is necessary to achieve fibre individualisation and in the case of an intermediate licker-in, such an intensive carding surface is neither present nor achievable practically.

1.6 Control of carding quality

The quality of the output of the card, which is the sliver, is generally expressed in terms of

1) its freedom from trash and dust,
2) number of neps still present and
3) the regularity of weight per unit length, both short and long term.

The first two measures define the efficiency of carding.

1.6.1 Neps, their definition and origin

Textile terms and definitions [48] define a 'Nep' as a small knot of entangled fibres that usually comprises dead or immature fibres. According to ASTM definition, 'A nep is one or more fibres occurring in a tangled and unorganised mass'. Neps in cotton continue to be a major problem in the cotton yarn manufacturing process. The two main factors affecting nep formation are fibre characteristics and mechanical processing. The mechanical processes affecting nep formation include ginning, opening and blending, carding, combing, drawing and spinning [49]. Neps are associated with poor yarn and ultimately with poor fabric appearance and have an effect on yarn uniformity and dyeing quality [50].

Neps in the raw material can be classified as mechanical neps or biological neps [51]. Mechanical neps are those made up of only fibrous material containing at least five or more fibres. Neps containing foreign material such as seed coat fragments, leaf or stem materials were designated as biological neps. A third category of neps found on the surface of the dyed fabrics was named pancake type neps. This type of nep appears as light or white spots in the finished fabric.

Neps occur more often in finer and less mature cottons. Immature fibres contribute to 'neppiness' because they have thin walls leading to a lowering of the micronaire value of cotton [49]. In one study, it was found that the average maturity of fibres in a mechanical nep was well below 50% [51]. It was also found that over 90% of the neps contained some immature fibres, while 50% of all the neps were composed entirely of immature fibres.

The neps containing seed coat fragments (biological nep) occurred in only 13% of all the neps studied [51]. The seed coat fragments form the nucleus of a biological nep, with fibres attaching themselves to the surface of the seed coat fragments. Seed coat neps are generated when the seeds become pulverised mostly during ginning. The attached fibres make this type of contamination very difficult to remove, as these fibres carry the seed along with the flow of the material and the seed particles are unable to fall out during opening [52]. As far as the third category of neps (pancake type) are concerned, it was found in one study [51] that this type accounts for a major portion of the total fabric neps. They found that these neps typically contain immature, undyeable fibres. It was opined that these neps could be the result of contaminated cottons for example with honeydew or improper crush roll settings or a high incidence of motes (aborted ovules) in ginned cotton.

Leifeld [52] further classifies the mechanical or fibrous neps into knops and neps. Knops or burls are fibre entanglements larger than about 1 mm, while neps are fibre entanglements less than about 1 mm.

Ginning conditions that influence nep formation are the ginning process itself, the amount of lint cleaning, heat history and the amount of energy input into the individual fibre [49]. In one study [49], it was found that ginning using three tower driers and two lint cleaners significantly increased the amount of card web neps compared with one lint cleaner and without using heat for drying. It was also observed that with finer cottons, increasing the card licker-in speed increased the card web neps. A closer flat-cylinder setting, on the other hand, reduced the web neps. It was also found a good correlation exists between the card web neps and the yarn neps. Figure 1.28 shows the neps in the card sliver over neps in the raw material [53].

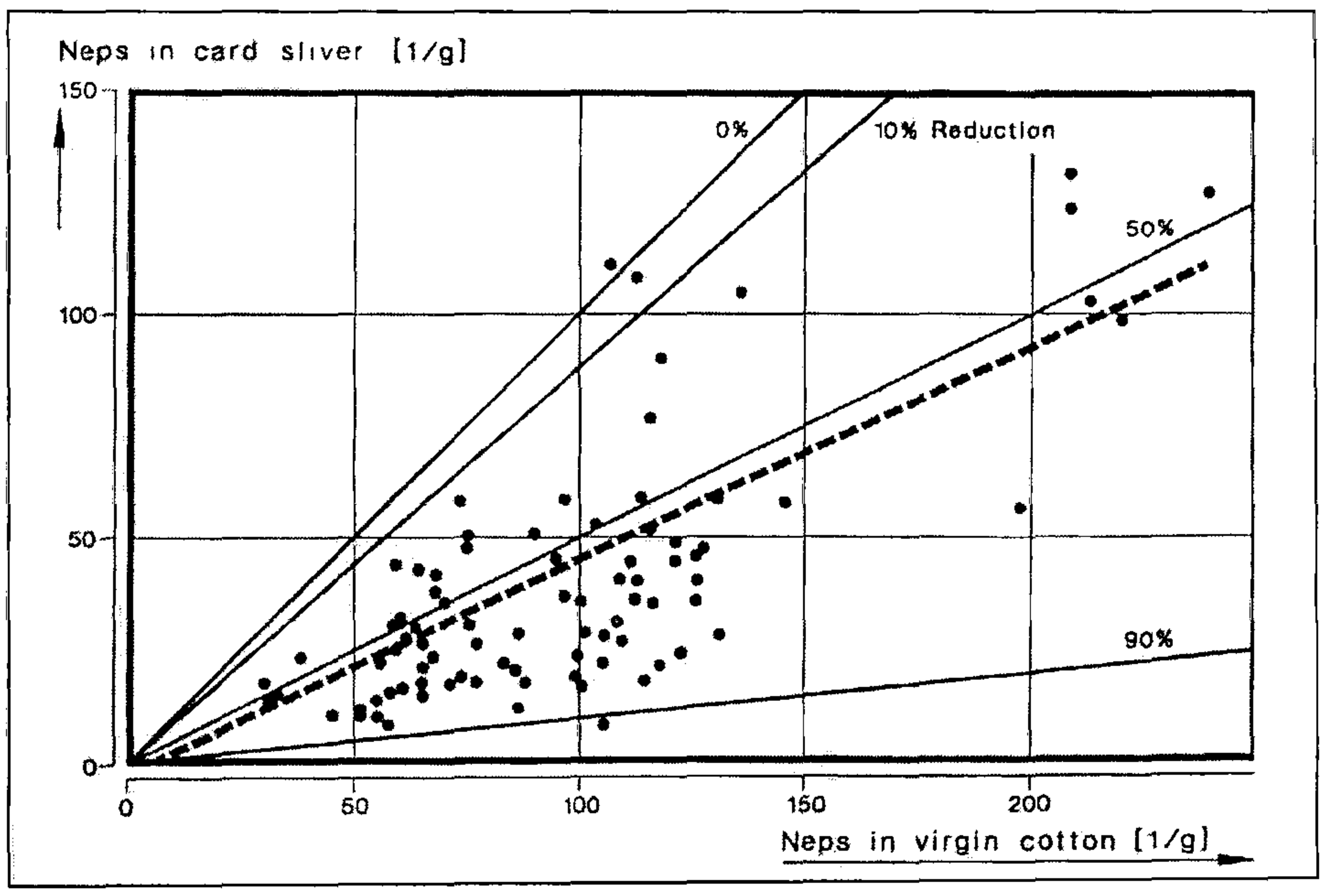


Figure 1.28: Card sliver neps vs. raw material neps

1.6.2 Cleanliness of card sliver

Cleanliness or freedom from foreign matter, especially trash particles, is one of the major factors that is critical in determining not only the yarn and fabric appearance, but also the running performance of the spinning machines. About

30% of yarn breaks in the spinning processes have been traced to the presence of the trash particles [52]. Therefore, it is clear that this has become a critical parameter for modern spinning processes, as spinning speeds are increasing day by day.

A modern card can clean over 90% of trash in the in-feed and similarly a card can also remove a large amount of micro-dust present in the feed material (Figure 1.29) [1]. It removes about 65% of the micro dust in the feed. In spite of the use of modern preparation equipment with intensive cleaning action, the card is still the machine with the greatest cleaning effect. The availability of modern testing instruments permits studies to be made of trash removal efficiency by size (like MDTA or AFIS). Card cleaning efficiencies were shown to be very much dependent on the particle size. In one of the studies, it was shown that 62% of particles over 500 microns were removed, while of the particles under 500 microns only 17% were removed [54].

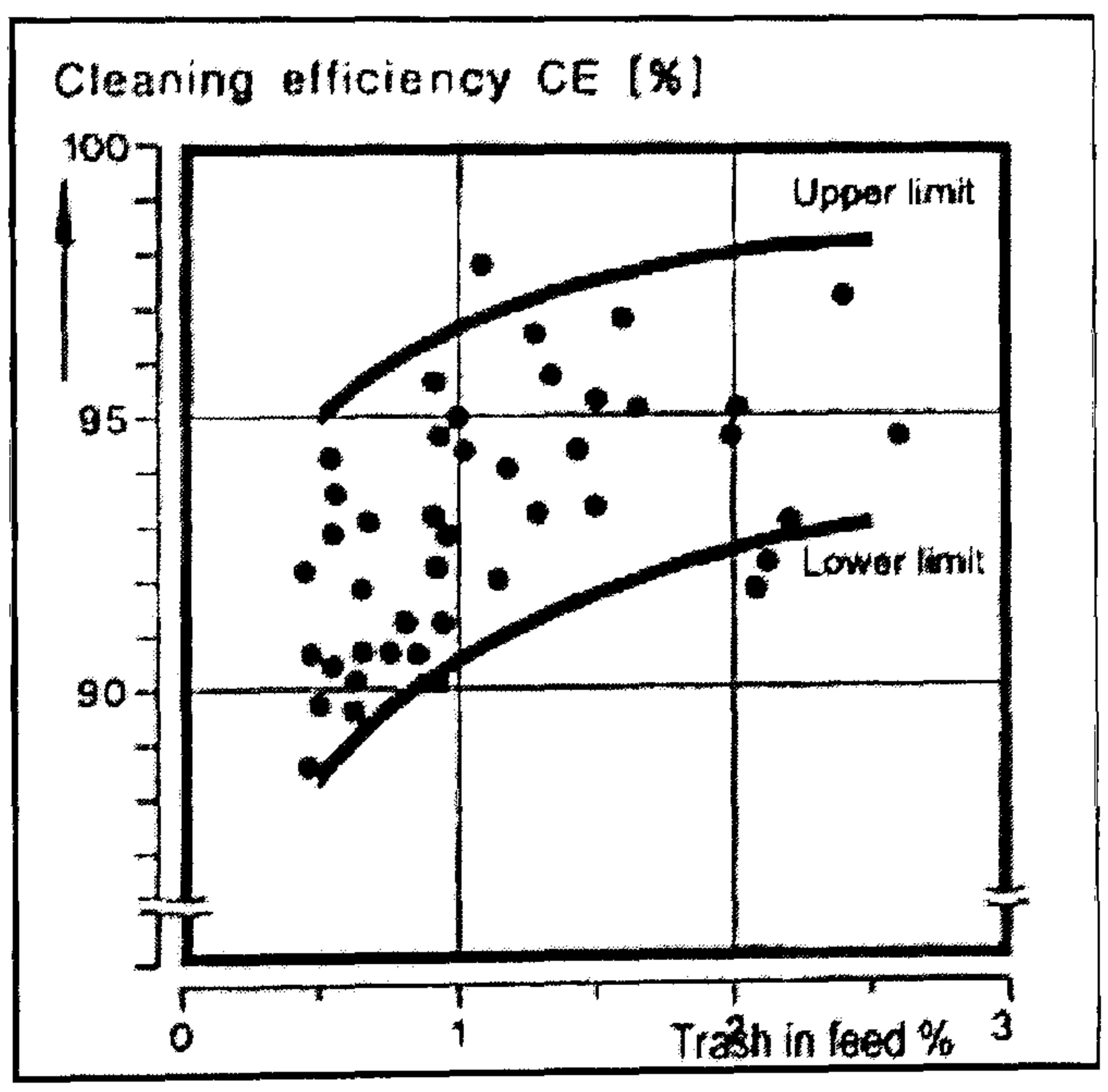


Figure 1.29: Cleaning efficiency of a modern card [53]

Modern cards are equipped to extract the finest of trash particles. The cards use every opportunity presented to extract the trash particles released after every opening stage within the card; under licker-in, after pre-carding segments on the back of the cylinder, after the cylinder-flats zone and under the cylinder. Licker-in with mote knives and opening segments cleans about 30% of the trash in the feed and similarly trash ejection arrangements on the cylinder and the revolving flats remove about 90% of the remaining trash [55]. An attempt is made to crush out the remaining trash particles by using crush rollers at the web delivery point, so that they fall out in the subsequent processes. It has now become possible to achieve <0.1% trash levels in the sliver. Use of higher cylinder surface speeds have helped to improve the cleanliness of the sliver [56]. Use of efficient suctioning arrangements further enhance the removal of trash and dust particles.

1.6.3 Card sliver uniformity

Sliver uniformity can be expressed in two ways. One is the short-term uniformity or the so-called Unevenness % and the other is the long-term uniformity in linear density or the sliver count. Stringent requirements of the yarn market in terms of count variation has forced the mills to exercise control over the linear density of the intermediate products right from the early stages of processing, i.e. from the blow-room itself. However, fine control over the sliver count is possible only at the carding stage.

Cards are equipped with auto-levellers, which monitor the linear density of the card feed at the feed roller and at the delivery. Continuous correction of the feed roller speed is applied to ensure medium and long-term uniformity of the sliver count. In some modern cards (e.g. Truetzschler DK 903 card), an attempt has been made to improve the short-term irregularity and fibre orientation by using a drafting arrangement at the coiler. The draft is varied to compensate for the variability in sliver.

Though card sliver's short-term uniformity (linear density variability) does not actually affect the yarn count variability significantly, it is one of the indicators of the health of the card. This is because the short-term sliver uniformity is considerably influenced by the condition of metallic clothing of the cylinder/ doffer/flats, the mechanical condition of the drive elements and the choice of carding parameters like card drafts. Therefore, mills regularly monitor the sliver uniformity both in the short and long term, in addition to monitoring of neps and cleanliness of the sliver.

1.6.4 Carding quality – A Spinner's challenge

In the textile machines of the future, it is expected that the consistency of the output quality will increasingly be critical [57]. There are a number of critical factors that influence the quality of the carding process and the most important are given below.

1. characteristics of raw-material
2. feeding matt openness.
3. feed matt linear density.
4. efficiency of pre-opening.
5. choice and condition of card clothing.
6. choice of process parameters in carding.

1.6.4.1 Characteristics of raw material

It is a well-known fact that it is easier to card coarse, short staple cotton than fine, long staple cotton. For the same linear density, the number of fibres in the card feed increases as the fineness of cotton increases. This increase in the number of fibres together with the slenderness of the fibres demands a more gentle, but intensive opening of the fibres. Coarse fibres can be carded at higher rates, as they are easily carded and less susceptible to damage.

1.6.4.2 Feeding matt openness

The higher the degree of openness of the fibrous matt fed to the card, the smaller the tuft size in the matt. Therefore, fibres are easier to separate at the licker-in. When the fibres are thoroughly separated prior to the cylinder, more effective carding can take place between the cylinder and the flat. The carding quality in terms of nep removal, cleaning and uniformity of sliver improves [58]. A study carried out at the Institute of Textile Technology, Charlottesville, on the carding of rayon staple found nep removal and Uster CV% were significantly improved when the card matt was more open. This study also found that better yarn quality was possible in terms of strength, evenness, yarn appearance, imperfections and infrequent faults.

1.6.4.3 Feed matt linear density

Cards are best suited for drafts between 100 and 120 [58]. The feed matt weight variation therefore needs to be controlled to reduce the variation of the draft from the set optimum, due to auto-levelling. Too much variation in the draft will have an effect on cleaning, nep removal and alignment of fibres in the card sliver [58]. Inch to inch variability of the feed matt translates into metre-to-metre variation in card sliver, which can be related to count variation in the yarn.

1.6.4.4 Efficiency of pre-opening

It is well established that the licker-in zone can help or hurt the quality of the sliver; effective separation of the fibres allows the cylinder to do its job, but over aggressiveness can damage the fibres [58]. The licker-in zone should ensure that well opened, evenly distributed tufts reach the surface of the cylinder. The performance of the cylinder-flats assembly, and the quality of card web, depend on the efficiency of the taker-in at separating the flocks into individual fibres and eliminating extraneous matter and neps [32].

The efficiency with which the fibrous material is opened in the taker-in assembly depends to a large extent on the parameters of the feed table and those of the saw tooth clothing of the taker-in [19]. Optimum licker-in speed and the settings used in the licker-in zone depend on the characteristics of the fibre, throughput rate of the card and openness of the feed matt. Since fibres transferred to the cylinder contain a smaller number of tufts, fewer fibres are deposited on the flats, thus reducing the flat strips, the fibre density on the cylinder and nep formation. Trash and fragments are likely to be absorbed by the flat clothing [28]. It has been shown that higher licker-in speed could reduce the rotor deposits in rotor spinning [59]. Good pre-opening also permits the use of flats with a higher number of points of finer wire quality [11]. Obviously, higher point density means more intensive carding action and better sliver quality.

1.6.4.5 Choice and condition of card clothing

The carding work on the fibres is a function of the point index, the point angle, the cylinder speed and the flats-cylinder setting [60]. All these parameters vary according to the raw material type, the type of card, the kind of feed, method of spinning, and end use of the yarn [18]. For example, by using a greater density of pinning on the cylinder for finer Russian cotton, the number of neps was significantly reduced, whereas, with a coarser and cleaner Egyptian cotton, no difference was observed. A trend was also observed that for dirty fine-stapled cotton, better results are obtained with finely pinned flats [18]. Again, clothings with moderate point density were found to give very good carding results at an appropriate cylinder speed [60], which indicates that point indices are not absolutely essential for achieving good carding results. Similarly, in one of the experiments, the yarn strength was found to decrease with increase in carding angle, while shorter tooth height was found to increase the yarn strength [60]. The specification of the card clothing needs to be determined after a long and tedious research to ensure the highest quality of web and the least number of neps [18].

As the condition of the cylinder clothing becomes dull, the carding quality also deteriorates. Dull flats can prevent neps from being removed, but loaded flats can be totally ineffective. Loaded doffer wire can cause holes in the web, which generate small slubs and neps in the card sliver [58]. Therefore, the condition/sharpness of clothing of the carding machines needs to be inspected whenever the quality of web goes below the required levels and the clothing ground whenever it becomes necessary.

1.6.4.6 Choice of process parameters in carding

Choosing right settings, speeds and throughput rates is extremely critical in determining the quality of the card output. There are no universally acceptable parameters for every type of cotton that is produced or for that matter for different man-made fibres used. It has been observed that no two mills use the same parameters for processing similar types of cotton, even with a similar type of carding machine. This is because the quality requirements, the quality of the pre-carding processes such as ginning and blow-room, correct process balancing for production etc. differs from mill to mill. Every quality-conscious spinning mill determines the right speeds and settings for particular cotton after repeated experimentation over a long period. Figure 1.30 illustrates the change in carding sliver and yarn quality with increasing rates of production [39].

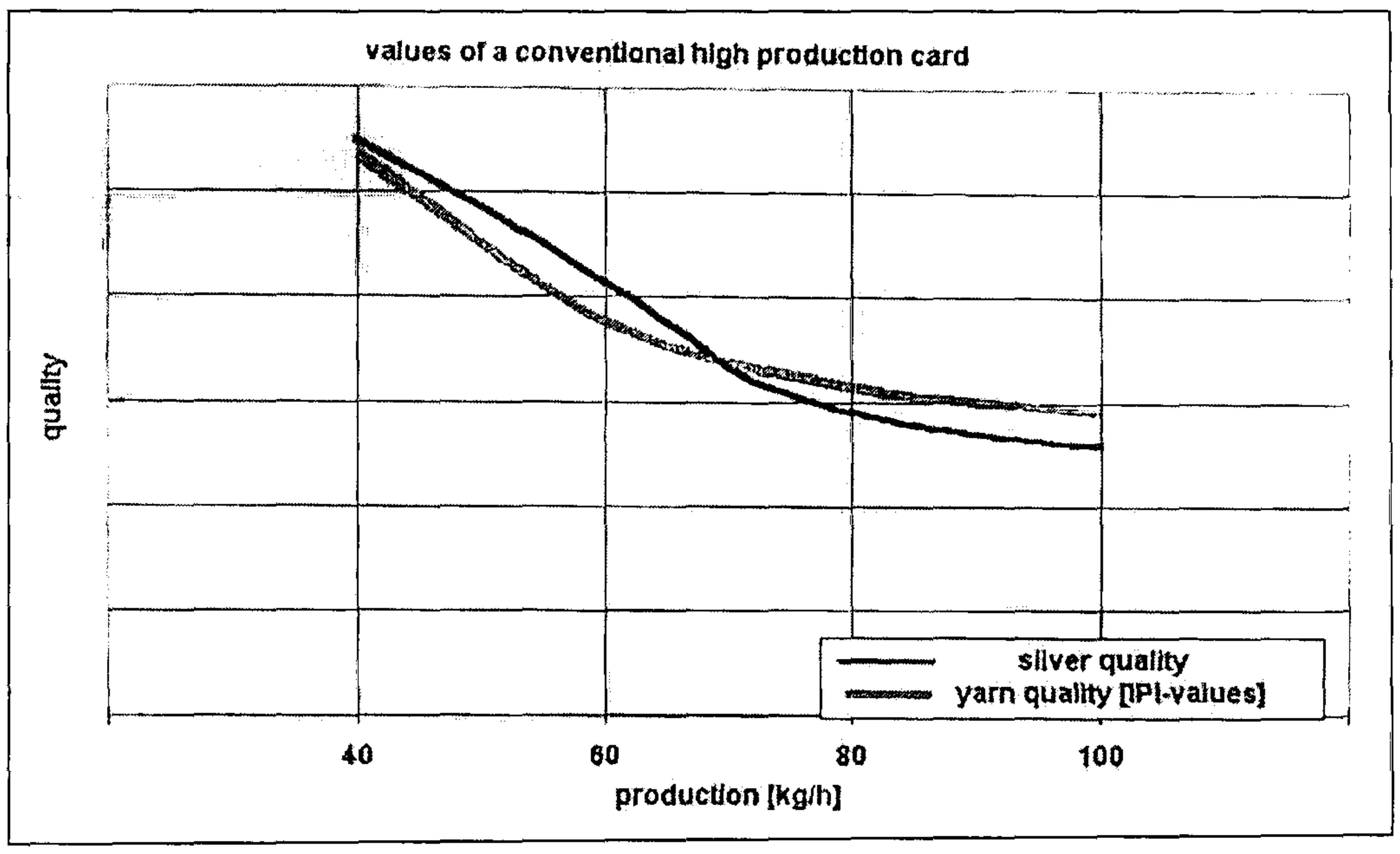


Figure 1.30: Quality vs. Card production rate [39]

The most important settings in the card are those of feed plate-licker-in setting, between the cylinder and flats, and the cylinder and the doffer. Other settings like those between the pre-carding and the post carding elements of the cylinder are important, but not as critical as those mentioned previously. As far as the speeds are concerned, the speeds of licker-in, cylinder, flats and doffer are very critical in determining the carding quality. For example, trash in card sliver decreases by

50% as a result of the centrifugal force involved in increasing the cylinder speed from 300 rpm to 600 rpm [24]. However the optimum cylinder speed is dependent on the cleaning propensity of the cotton used [56]. Micro-dust removal is also effective at higher cylinder speeds resulting in lower rotor deposits in rotor spinning [59]. On the other hand, raising the cylinder speed is more detrimental to the staple length than increasing the licker-in speed and yarn tenacity decreases at higher speeds. Increasing the licker-in speed was found to increase the waste under the licker-in, with loss of lint being the main cause for this increase [61]. Interestingly, when the feed weight was increased for the same licker-in speed, the waste removed by the licker-in decreased significantly with the degree of cleaning done by the licker-in remaining the same [62]. The short fibre content in the sliver for long staple cotton was found to increase with an increase in cylinder speed [60]. In one study [59], the yarn tenacity was found to decrease by 5% when cylinder speed was increased from 260 rpm to 380 rpm and by 10% when the speed was further increased to 600 rpm in the case of ring spinning. In case of rotor spinning, the tenacity decreased when the speeds were raised above 480 rpm.

There are a few universally accepted factors in carding.

1. In general reduced carding throughput rates result in improved carding quality.
2. Higher cylinder speeds improve the cleanliness of card sliver.
3. At a given production rate, finer slivers lead to better quality of sliver.
4. The optimum surface speed ratio between licker-in and cylinder is in the range of 1:1.8 to 1:2.2. So, the speeds of the cylinder and the licker-in should be chosen after considering this factor.

1.7 *Fibre arrangements in yarn*

1.7.1 Arrangement of fibres in card sliver

Neps, cleanliness and evenness of card sliver are not the only satisfactory indicators of carding quality. In addition to these measures, 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 [63].

Though mechanical carding was first conceived 250 years ago, much of what takes place between the working surfaces of a modern revolving flat card remains a matter of conjecture [64]. There is no direct method to observe some of the fibre dynamics in areas of the carding processes like the cylinder-flats or between the cylinder and the doffer, without interfering with the normal carding process. Therefore, it is necessary to rely on inferences based on indirect evidences for our understanding. A systematic study of the arrangement of fibres in card sliver is one such evidence, which could throw some useful light on the actual happenings within the card [64].

Fibre arrangements can be studied using a tracer fibre technique, which is explained in section 1.7.4. The most important features of each tracer fibre are its extent and its disposition within the sliver. Morton and Summers divided the tracers found in card sliver into five groups [64]. The groups and the percentage of fibres in each group observed by different workers are given in Table 1.2. Other researchers have given estimates on fibre hooks, but only the fibre configurations studied on a regular card are given here and not the estimates with miniature carding machines.

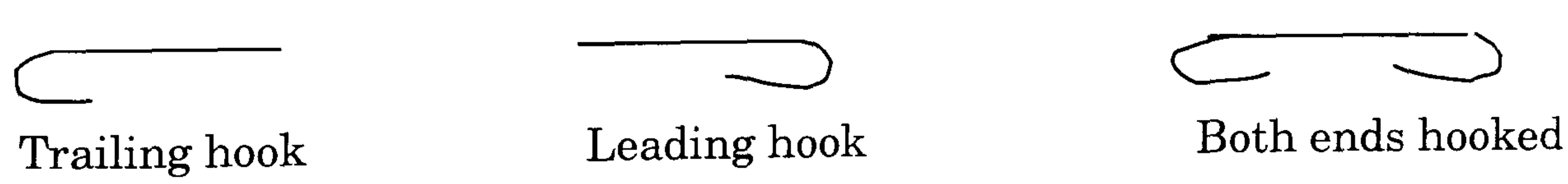


Figure 1.31: Fibre Hooks

Table 1.2: Fibre hooks in card sliver

Groups		1	2	3	4		5	6
	Fibre	V	C	C	EAC*	GC*	C**	C***
I	Leading Hooks	16 %	10%	19%	7%	8%	7%	19%
II	Trailing Hooks	48%	42%	47%	47%	43%	55%	47%
III	Both ends hooked	13%	8%	8%	13%	16%	14%	8%
IV	Not hooked	21%	25%	24%	22%	16%	NA	23%
V	Others	2%	15%	2%	10%	18%	NA	3%

1. Morton and Summers [64]
2. Morton and Yen [65]
3. Garde *et al* [66]
4. Wagle and Govindarajulu [67]
5. Ghosh and Bhaduri [68]
6. Wakankar *et al* [69]

V – Viscose
C – Cotton
C – Giza 30 cotton, EAC – East African cotton
* Readings with Cylinder-doffer setting 5 thou
** Cylinder speed 315 rpm, Carding rate 7 lb/hr
*** Doffer speed 10 rpm

As can be seen there is some variation in hook distribution among these findings of different research workers. These differences could be attributed to the raw material, the type of carding machine and the carding parameters used. It was confirmed [68] that processing parameters such as cylinder and doffer speeds, sliver weight and production rates had a significant influence on the fibre hooks present in the card sliver. It has been confirmed that on an average about half of the fibres have trailing hooks, about one sixth of the fibres have leading hooks, another one sixth are hooked on both ends and about one fifth of the fibres are not hooked [6].

1.7.2 Hook formation in carding

There have been a number of hypotheses relating to the mechanism of hook formation in carding presented between 1949 and the early 80s, though it is surprising that no recent study has been published with respect to hook formation on the latest generation of carding machines.

It was proposed that fibres on the cylinder can be classified into two groups [64]: firstly those which are held in position by being hooked round the cylinder wires, and the other being those which, though not hooked round the cylinder wires, are held in position by contact or entanglement with those that are. On reaching the doffer, the leading ends of the second group of fibres will be arrested at their most projecting part possibly by actual contact with doffer wire and the rest of the length will be swept downward by the rapidly retreating cylinder (Figure 1.32). This could lead to trailing hooks. Apparently, other workers also agree with this theory [69, 70].

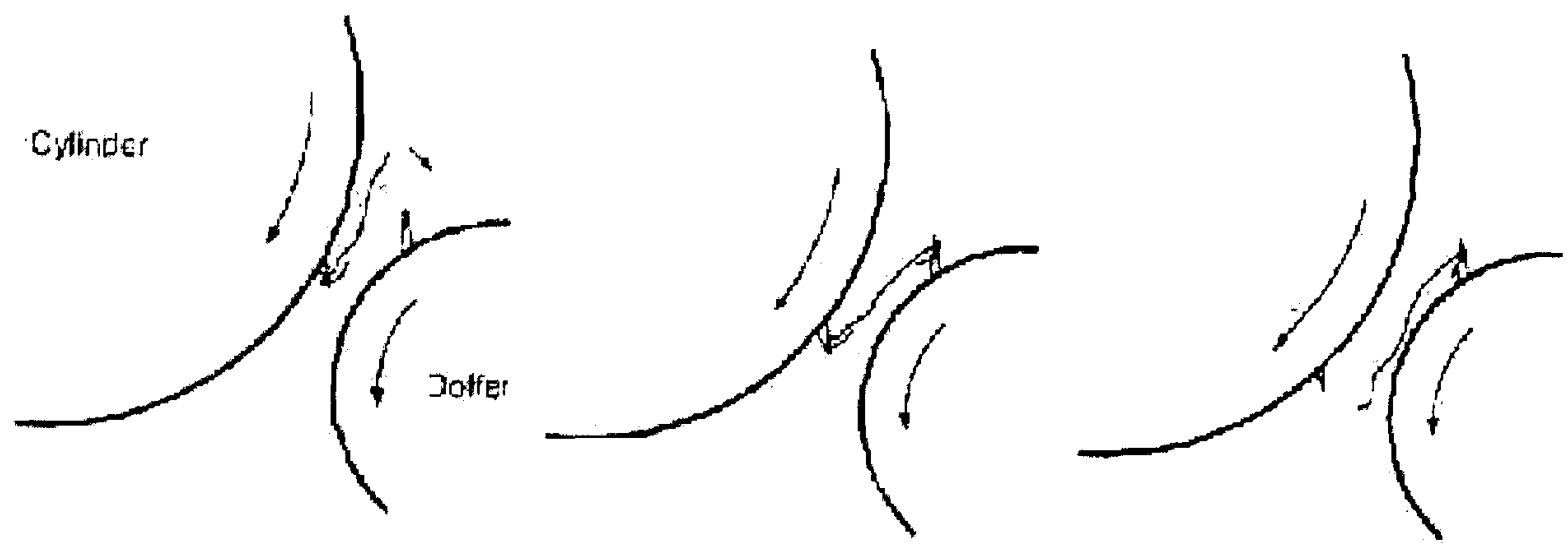


Figure 1.32: Formation of trailing hooks

It was further postulated [70] that when the front end of a fibre moving with the velocity of the cylinder comes in contact with the relatively slower moving doffer surface, it buckles, and if the fibre is loosely held by the cylinder, it gets transferred without reversal, thus forming leading hooks. According to this hypothesis, the probability of such a fibre transfer from the cylinder to the doffer without reversal of ends depends largely on the nature and extent of positive control exercised by the cylinder on the rest of the fibre; an increase in lead on the operational layer of the cylinder would decrease the magnitude of positive control that cylinder wires have over individual fibres. In such a state, fibres will transfer more easily without reversal, leaving the leading hooks as leading hooks on the doffer surface. This is entirely in agreement with the proposition of Morton and Summers [64], who also felt that this could lead to both leading hooks and hooks on both ends.

While the propositions of Morton and Summers were merely theoretical based on tracer fibre configurations in card sliver, later workers [69-71] made some practical observations on the card cylinder, before the fibres are transferred to doffer. One study [71] used dyed yarns as tracers and observed them under UV light on the cylinder. In this study, it was found that transfer of fibres from cylinder to doffer takes place both with and without reversal of fibre ends. Similar observations were made in another study [70], which used fluorescent tracer fibres for the experiments. It was also observed that during transfer between cylinder and doffer, 50% of fibres reverse their direction. Many of the observations made in two studies [70, 71] are quite similar to each other and the following is a summary of those observations:

- In general, there were a very large number of leading hooks and very few trailing hooks on the cylinder surface.

- Nearly two thirds of the trailing hooks are formed during transfer; one third originated from leading hooks on the cylinder that reversed during transfer, one sixth from leading straight ends on cylinder that got hooked in the trailing direction during transfer. Around half of the trailing hooks originated from trailing straight ends on the cylinder that got hooked during transfer.

- Nearly a third of the leading hooks originated from trailing hooks on the cylinder that reversed during transfer and more than one third were originally leading hooks on the cylinder that got transferred without reversal. Nearly half of the leading hooks in the card web were originally straight ends that got hooked in the leading direction during transfer from the cylinder to the doffer.

- Nearly half of the leading hooks on the cylinder retained their hooks in the web, whereas the hooks on the other fibres disappeared. It was postulated that for the fibres that did not undergo reversal, (leading hooks originally on the cylinder) became straightened by the combing action of the cylinder while being held by the doffer.

It was suggested [70] that the number of fibres with leading or trailing hooks in the web would depend on the balance of 3 factors: a) the number of hooked fibres transferred from the cylinder to the doffer with or without reversal, b) the number of straight ends hooked during the transfer with or without reversal and c) the number of ends straightened due to the carding action between the cylinder and the doffer. The magnitude of these 3 factors, and hence the hooks are influenced by fibre, process and machine factors.

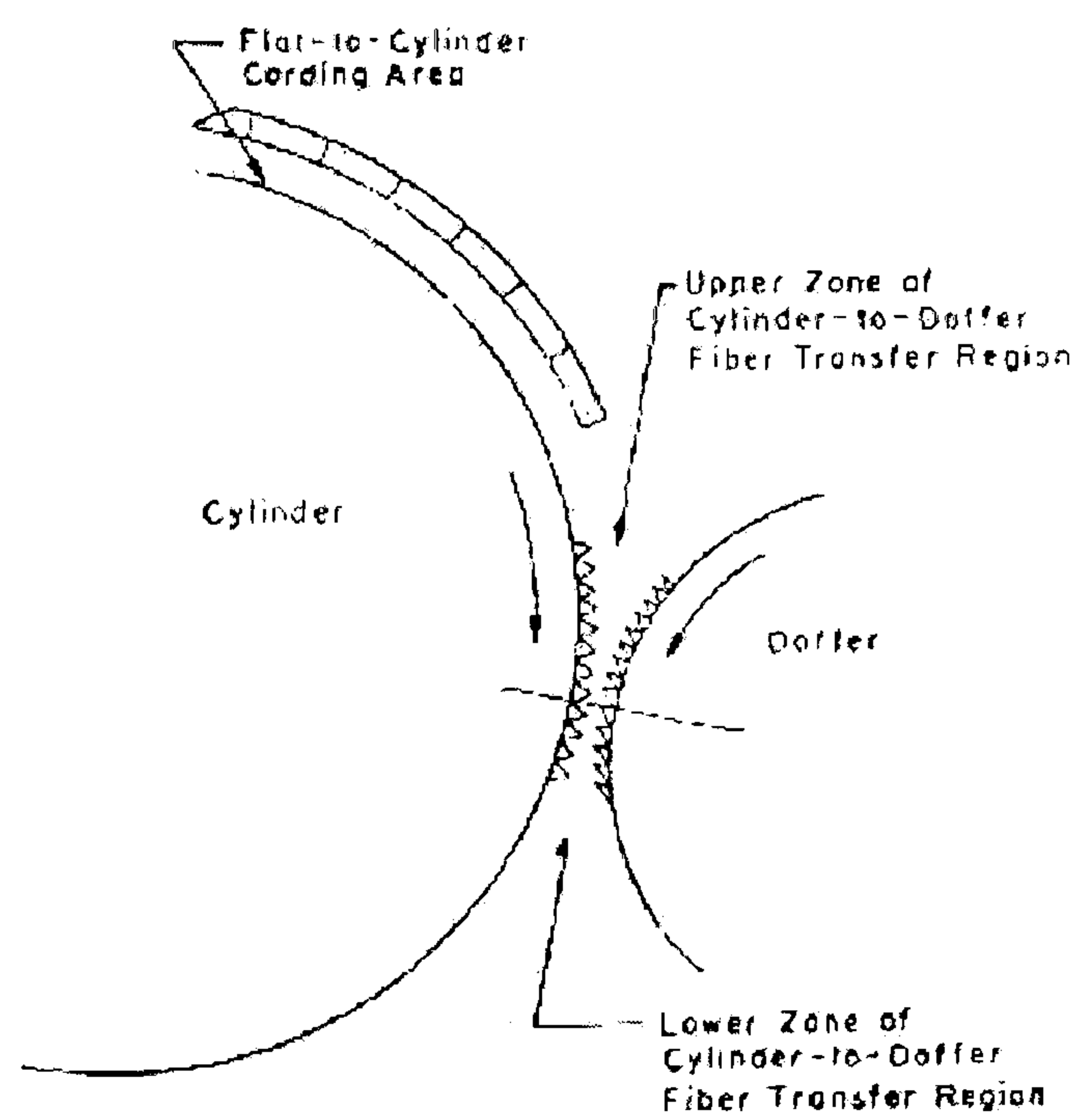


Figure 1.33: Cylinder-doffer fibre transfer regions

It was proposed [72] that the type of fibre transfer determines the sliver orientation. If the conditions are such that the fibres transfer predominantly early, i.e. in the upper zone of the cylinder to doffer fibre transfer area (Figure 1.33), then there will be a relative increase in the trailing hooks, which decreases the overall fibre parallelisation. It was also suggested that this upper zone transfer could be caused by an increase in cylinder speed, an increase in sliver weight, a decrease in the cylinder to doffer setting and, certain fibre characteristics namely coarser fibres with good resiliency and low friction. But transfer later in the lower zone results in fewer trailing hooks and better fibre orientation.

1.7.2.1 Effect of carding variables on fibre hook formation and fibre order

a) Orientation of the feed material

One of the studies [73] focussed on the degree of order / disorder of the feed material and its influence on the fibre disorder in the carding sliver. Laps that had different degrees and types of fibre disorder were prepared, i.e. normal laps using raw cotton, laps with card sliver (laps produced with card sliver fed in normal and reversed directions) and also combed sliver. The findings of the study are given below.

1. Irrespective of the type of feed, the percentage of hooked fibres in the outcoming sliver was fairly high, and varied only between narrow limits. Further, in every case the trailing hooks were the majority as in normally processed sliver.

2. When laps made with card slivers were fed with card sliver in normal and reversed directions, little difference was noticed with respect to the percentages of trailing and leading hooks, in spite of large variations in the percentages of such hooks fed to the card.

3. With combed feed, the percentage of trailing hooks is significantly reduced while that of leading hooks is significantly increased. The general disorder is significantly less and this can be ascribed to greater fibre extent, better alignment, and smaller amount of short fibres for example.

It was opined that the card more or less obliterates the fibre arrangement in the feed and gives it a treatment, which results in a fairly constant percentage of hooked fibres in the sliver.

b) Licker-in speed

Licker-in speed was found to have no significant effect on the pattern of hook formation [68].

c) Cylinder speed

When the cylinder speed was increased at a constant production rate, the leading hooks and fibres with hooks on both ends decreased. No clear trend was observed with regard to trailing hooks and fibres without hooks showed a significant increase at high cylinder speeds [68].

d) Doffer speed

At a constant production rate, when the doffer speed was increased (by making the sliver finer), trailing hooks increased while leading hooks and fibres with both ends hooked decreased [68].

As the rate of production increases, there is increasing tendency towards fibre disorder and the number of leading hooks in the sliver increases with the rate of production; the number of trailing hooks shows a decrease at a high rate of production [69] [74]. Minority (leading) hooks increased and majority (trailing) hooks decreased with an increase in carding rate at all cylinder speeds, more so at lower cylinder speeds than at higher speeds [74]. Every cotton has its own distinctive fibre-hook formation pattern at different carding rates.

It was also found [69] that flats do not play any significant part in the formation of fibre hooks. It was also opined [64] that the doffer comb could cause some of the leading hooks, which was disproved by other researchers [69]. It was found that the doffer comb, its speed or methods of doffing (roller doffing device or doffer comb) have no effect on hook formation.

1.7.3 Arrangement of fibres in yarns

As with card sliver, Morton appears to be the first to have published a study of the fibre arrangement in yarns using a tracer fibre technique. Morton and Yen [75] state that an idealised yarn structure which is built up of a number of superimposed concentric layers could not exist in practice. The ideal arrangement of fibre within the yarn and the actual disposition of the fibre within the yarn are shown in Figure 1.34.

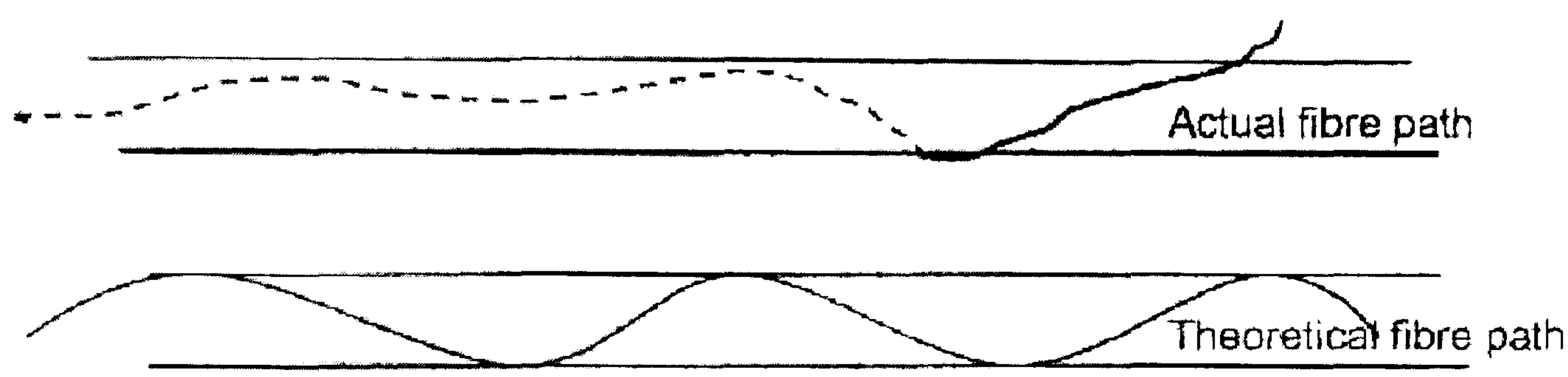


Figure 1.34: Actual and Ideal fibre paths in the yarn

It was stated [75] that during twisting, the fibres of a yarn are in varying states of tension depending on the positions they occupy, those lying on the surface being at a higher tension than those near the core. This would lead to tighter filaments trying to migrate to the core, while the slack ones try to move to the surface. Therefore the fibres or filaments constantly change places, moving from the outside of the yarn to the inside and back again, numerous times.

Fibre migration in yarns results from the interaction of two mechanisms [76]: one depending on the stress differences in fibres, and the other one depending on the initial roving twist and, consequently on the geometry of the twisted fibre band. It was proved experimentally that the stress mechanism predominates in ring spinning staple fibres.

Kasparek [77] quoting Peyaskhov states that in actual yarn, the fibres are so distributed that the fibre segments are positioned at different distances from the yarn axis, passing in effect through various layers. Peyaskhov concluded from his experiments that firstly there was no law governing the transfer of a single fibre from the surface to the yarn core and vice versa and secondly, within a yarn, fibres generally assume a helical shape on the surface of a rotary paraboloid. Kasparek also quoted Belicin, who showed that each fibre changes its position relative to the yarn axis and moves from one zone to another across the yarn cross-section. Some fibres change their positions several times in a single zone and there are also fibres that never appear (in their whole length) on the surface of the yarn.

Kasparek [77] advanced a method to study the fibre migration that takes into account the hooks, loops and the fibre protrusions out of the yarn body. This method was based on the fact that the whole fibre length cannot contribute to the yarn strength, but only the part of the fibre that is spun-in, which should have a significant effect on the physical properties of yarns.

A term 'fibre spinning-in coefficient' is used, which is defined as the ratio of the spun-in fibre length (length of the fibre within the body of the yarn) to the overall length of the fibre. This spinning-in coefficient will range within the limits

$$0 \leq K_F \leq 1$$

where K_F is the spinning-in coefficient.

The higher the value of K_F, the greater is the incorporation of the fibre within the yarn and hence the greater is its contribution to yarn strength. It was proposed that fibre shapes in the yarn could be classified into ten standard typical fibre shapes used for quick classification of fibres (Table 1.3) as shown in the Fig 1.35.

Table 1.3: Spinning-in Coefficient K_F [77]

Class	K_F	Class	K_F
0	1.00	5	0.40
1	0.95	6	0.20
2	0.90	7	0.08
3	0.80	8	0.02
4	0.63	9	0.00

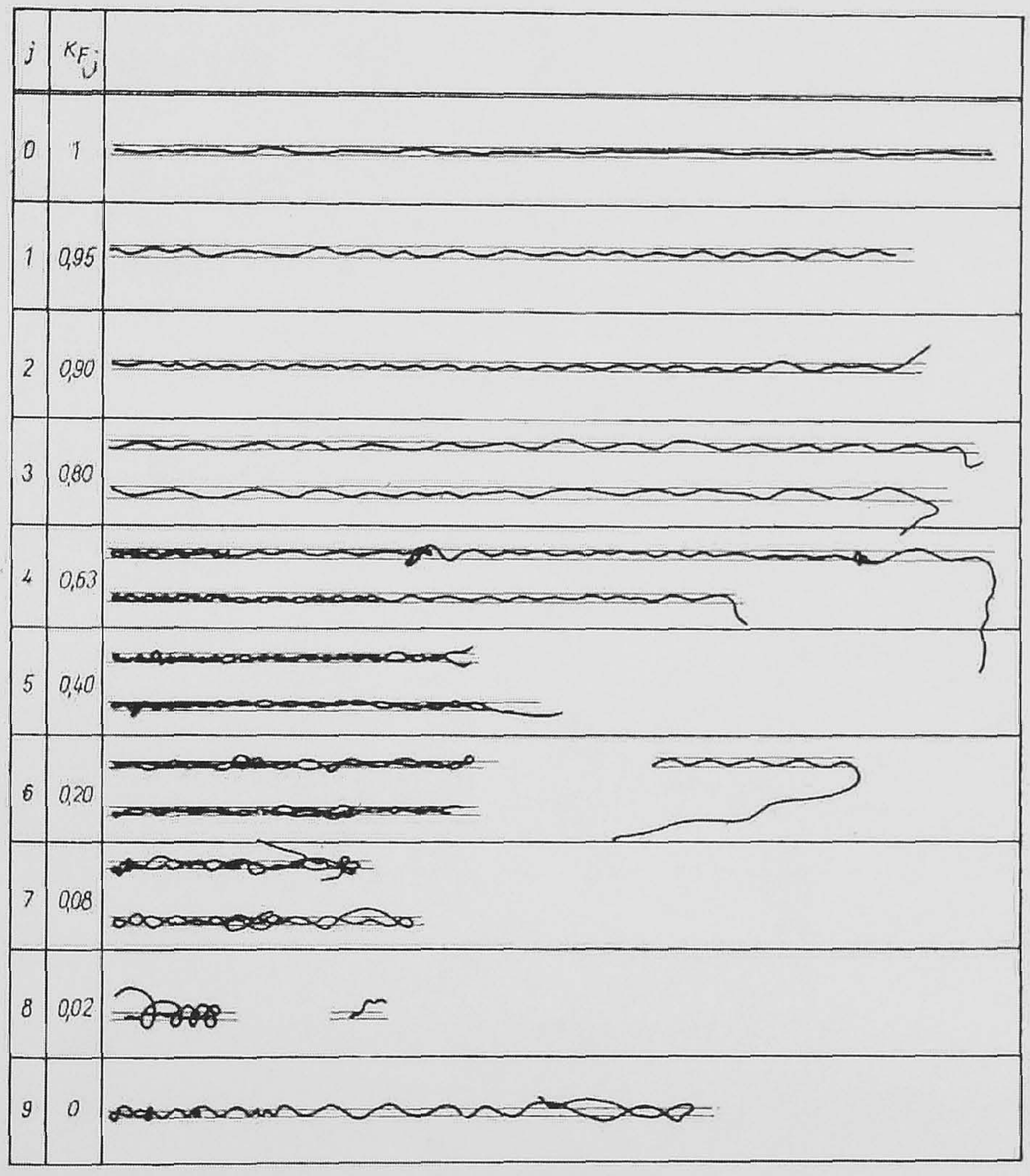


Figure 1.35: Typical fibre shapes and their Spinning-in coefficients [77]

The classification used in Figure 1.35 to find the values of the spinning-in coefficient for carded, combed and rotor spun yarns are given in Table 1.4. From these results it is clear that fibres are spun better into the structure of the yarn in ring spinning rather than in rotor spinning. It could also be seen that combed yarns have a higher coefficient than carded yarns, indicating that the fibres in combed yarn are better aligned with reduced hooks, loops, hairiness etc.

Table 1.4: Spinning-in Coefficient of different yarns

Yarn Count	Combed Yarn	Carded Yarn	Rotor-spun Yarn	
			BD 200 Machine	Old OE Machine
19.5 tex	0.757	0.659	0.512	0.414
31 tex	0.760	0.686	0.504	0.368

Fibre arrangements in yarns have been studied exhaustively over half a century, though the published work regarding hooks is minimal since interest was mainly focussed on the study of fibre or filament migration within the yarn.

Several studies have been conducted in fibre arrangements in yarn, the findings of which are given in Tables 1.5 and 1.6.

Table 1.5: Fibre Hooks in Yarn

Description	Nield and Ali [78]		Ishtiaque *et al* [79]	
	Ring Spun*	Rotor Spun*	Ring (normal) Yarn**	Ring (SIRO) Yarn***
Leading hooks	10%	31%	12%	12%
Trailing hooks	3%	13 %	9%	7%
Both ends hooked	NA	NA	6%	2%
Fibres with no hooks	74	43	68%	75%

* Spun using 38 mm viscose fibres at 65% RH

b** Spun using 38 mm viscose fibres at 4 mm spacing between rovings

*** Spun using 38 mm viscose fibres

Table 1.6: Fibre hooks determined by Rimmer [46]

	Rimmer [46]					
Description	Ring spun (Single Card, Single Licker-in)	Ring Spun (Single Card, Triple Licker-in)	Ring Spun (Tandem Carded)	Rotor Spun (Single Card, Single Licker-in)	Rotor Spun (Single Card, Triple Licker-in)	Rotor Spun (Tandem Carded)
Leading hooks	24%	24%	24%	28%	40%	28%
Trailing hooks	8%	12%	8%	8%	8%	8%
Both ends hooked	4%	4%	-	12%	12%	8%
Fibres with no hooks	64%	52%	68%	36%	20%	40%
Loops	4%	8%	-	16%	20%	12%
Others	-	-	-	8%	12%	12%

The above tables present an interesting picture of how the fibre arrangements in card sliver can influence the fibre arrangements in yarn, in spite of the large amount of drafts involved while converting the sliver into yarn. It can also be seen that compared to card sliver, there is a greater reduction in the number of hooked fibres and an increase in straight fibres because of the subsequent drafting. As with card sliver, there is a variation of the fibre hook level between different research workers who carried out the work during different periods on different carding machines on different cotton varieties, reinforcing the fact that the hook formation is a complex phenomenon.

As can be seen in Table 1.6, in general, the hooks are greater with rotor yarns than with ring spun yarns, while tandem carded yarn seems to be slightly better than single carded yarn. The amount of the fibres with loops are fewer (in case of rotor spun yarn) or absent (in case of ring spun yarn) for the tandem carded material. The tandem carded material also seems to show greater number of fibres with no hooks. It was found [46] that the fibres from the tandem followed a smoother helical path than single card (single licker-in as well as triple licker-in).

The single card with a triple licker-in arrangement produced more deformations in the fibre configuration than either single or tandem carded processed fibres. Rimmer [46] states that triple licker-in carded yarns exhibited more crimpy sections and had more fibres protruding from the body of the yarn than the single licker-in and tandem carded yarns. Another interesting phenomena is the presence of greater number of fibres with loops in rotor yarns and also in ring spun yarns that used a triple licker-in system in carding.

1.7.4 Tracer fibre technique

The tracer fibre technique used in studying the fibre configuration in slivers and yarns has helped in developing some understanding of the fibre dynamics in carding. It appears that the first to propose and pioneer this method for study of fibre configuration were Morton and Summers [64] in 1949. The principle technique established by them has become the basis of many other techniques.

In this technique, a small quantity of black dyed fibres (say 0.1%) are blended with the raw material prior to carding. The sliver or yarn is immersed in a medium (solution) that has a refractive index similar to that of the raw material. Thus the raw material is optically "dissolved" and the tracer fibres can be seen with enough clarity through a low power microscope and can thus be recorded.

1.7.4.1 Preparation of the tracer fibres

The black dyed fibres are essentially made from the same raw material (e.g. cotton). But before dyeing, the fibres are opened thoroughly using an opener (such as Shirley Analyser) so that dye absorption is uniform. After dyeing, the fibres are hand-opened and distributed evenly into the mix. It must be ensured that the tracer fibres are thoroughly blended with the raw material before the carding stage so as to ensure that the fibres are randomly distributed in the card sliver.

1.7.4.2 Selection of the medium

It is generally not an easy process to select the suitable medium or solution that has similar refractive index as the raw material. It is possible that there could be several media that have closer refractive indices to that of raw material. The following criteria would have to be considered before the selection can be made [65].

a. Stability of the medium under laboratory conditions.
b. Transparency.
c. Inertness to the fibre.
d. Toxicity and volatility.
e. Surface tension.
f. Useful life of the medium.

For example, cotton fibres have a refractive index of about 1.556 and methyl salicylate having a refractive index of 1.546 may make a good medium and has been used by some research workers in the past. However, in some instances, it may be necessary to mix the medium with another to improve the clarity of the tracer fibre. A dense medium is unsuitable for the tracer fibre work as the visibility of tracer is considerably reduced.

Many of the media are toxic or produce fumes and would need the use of a specially designed fume cupboard. It may also be required for the fibres to be immersed in the medium for sufficiently long duration to obtain greater clarity.

1.7.4.3 Recording of the tracer configurations

As stated previously, this involves the use of a low power microscope to look through the medium and the sliver/yarn to find the tracers. The tracers can be either recorded photographically or measured using pantograph tracing. Recording the tracer using a video camera has been adopted in the University of Leeds and depending on the fibre length, it involves photographing small (1.5 to 2 mm) but consecutive sections of the tracer fibres and consequently involves about 10 to 20 images to constitute one full fibre. It is also possible to recombine these images using image-editing software to produce a continuous trace that can be analysed.

1.8 Summary and Conclusions of Literature Review

Carding is one of the most important preparatory processes in the spinning of yarns; it is always referred to as the 'heart of the spinning mill'. Therefore, this process needs to be optimised to achieve the desired yarn quality. A review of literature on the history of short staple carding revealed how little the main carding components have changed, since Lewis Paul took out his first patent in 1748.

Demands to improve card quality and productivity have put enormous pressure on the manufacturers of carding machinery to improve card design features. This should be viewed in the light of the deteriorating quality of raw cotton with respect to maturity and trash content, which has been observed over the years. In the review, we saw that the productivity of the carding machine has grown from 4 or 5 kg per hour to over 100 kg per hour since the 1950s. The fillet card clothing has been replaced with metallic card clothing and doffer combs replaced with doffing rollers. These changes laid the foundation for high-production carding. There have been numerous developments with respect to the clothing design and a great improvement in mechanical precision and metallurgy, which permit higher rotational speeds and very close settings. In the review, we also saw that one of the most notable changes / improvements has been the development of the multiple licker-ins along with carding segments, especially the triple licker-in arrangement to improve the carding performance.

The review looked at the critical carding parameters that affect the carding process, especially, the design of the licker-in zone, which was studied in some detail. Several studies show that the licker-in zone design influences the card output and an efficient design would help to improve the carding quality and productivity.

The review also looked at neps, their origin and classification, and also how the card plays an important role in their elimination and control. It was discussed how optimising the carding parameters can reduce nep formation and also improve the cleanliness of the card sliver.

The final section of the review looked at the fibre arrangement in the sliver and the yarns. This section also discussed the different theories regarding fibre hooks formation. A number of theories were discussed and it could be concluded that carding parameters such as cylinder and doffer speeds, setting between them and carding rate play a significant role in determining the amount of trailing or leading hooks in card slivers.

1.9 Aim and Objectives of the present investigation

Increases in carding productivity have introduced several complex factors into processing of the fibres through the carding machine. The machines have become mechanically near perfect and highly automated incorporating online quality monitoring systems. Due to these technical advances, carding has reached a saturation point with respect to incorporation of new ideas or technologies and old ideas are being recycled in some form or the other. In spite of the developments, it is clearly felt in the cotton spinning industry that much more needs to be done in order to develop machines that can process all types of cotton with equal ease including the superfine and long cotton varieties. Further increases in productivity require a careful study of the existing technology so that those factors that are critical to quality and productivity are identified and new designs can be developed.

The pre-opening section of the carding machine has been recognised as contributing significantly to the quality of the carding output. The single licker-in arrangement has been found to be inadequate at high production rates because of the limitations in increasing the licker-in speed (due to possible fibre damages), to achieve the required degree of opening in the licker-in zone. Leading carding machine manufacturers have introduced three licker-in arrangements in their carding machines and they have been successful in increasing the carding productivity significantly. However, anecdotal evidence from industry suggests that not all cotton varieties can be processed with ease on cards with triple licker-in. In cases where it has been successful, there have been indications (in the work carried out at the University of Leeds earlier [46]) that fibres processed through a triple licker-in show greater fibre disorder in the yarns as well as in the fabrics giving them an increased pilling tendency.

Therefore in order to study the differences, it was important to look at the quality of yarns spun using the single and triple licker-in systems, look at the fibre configurations within the yarns and also to try to relate the results to the actual processes taking place within the licker-in zone.

The objective of this research is that with the knowledge gained, it will be possible to reach a better understanding of the fibre dynamics within the licker-in zone and how the dynamics reflect on the fibre, yarn and fabric quality. The rest of the theses will be presented as follows;

- Chapter 2 will look in detail at the test procedures and equipment used in evaluating different fibre, yarn and fabric characteristics.
- Chapter 3 will look at the effects of licker-in type, licker-in speed and productivity on the fibre, yarn and fabric quality.
- Chapter 4 will look at the fibre configuration within the yarns spun from fibres processed on the two licker-in systems.
- Chapter 5 will discuss the experimental findings of high-speed photography with the two licker-in systems.
- Chapter 6 will summarise and discuss the findings of the investigations
- Chapter 7 will discuss the scope for further research and conclude.

CHAPTER 2

Assessment of Carding Performance - Methods and Techniques

2.1 Introduction

When quality of carding is considered, it does not just mean the sliver quality, because efficient carding has a far-reaching influence in producing an acceptable end product, be it yarn or fabric. There are several techniques involved in determining the efficiency of the carding process, such as the measurement of neps and trash, and the uniformity in linear density of the card sliver. When the same sliver is spun into a yarn, the evenness of the yarn in terms of frequent and infrequent faults is important. As far as the fabric is concerned, qualities like fabric appearance and pilling tendency are more important, and, again these are influenced by the raw material and the preparatory processes such as carding and spinning.

Whereas the determination of neps and trash give us useful information on the state of the carding process, the best way to assess carding performance is to produce a yarn from the card sliver to assess its quality, while ensuring that post carding variables are not introduced.

Several yarn properties are influenced by the carding process, including: yarn unevenness CV%, number of thin and thick places, neps, hairiness and yarn strength, and although not a quality parameter, fibre configuration within the yarn structure can be added to this list.

This chapter reviews the test methods used for assessing carding performance including the apparatus and techniques.

2.2 *Testing Conditions*

Cotton fibres are hygroscopic and their properties change noticeably as a function of the moisture content. This is particularly critical in the case of cotton fibre strength, which increases with the absorption of moisture unlike many textile fibres that tend to get weaker. As a result, testing must be carried out under constant standard atmospheric conditions (a temperature of 20±2 °C and a relative humidity of 65±2%) [80]. Prior to testing, the samples must be conditioned under standard atmospheric conditions until their moisture content is in equilibrium with the surrounding atmosphere. To attain the moisture equilibrium, a conditioning time of at least 24 hours is required, 48 hours is preferred. For samples with high moisture content, conditioning time should be at least 48 hours unless the samples are preconditioned, so that the moisture equilibrium is later approached from the dry side [80].

Most of the fibre and yarn tests conducted on the samples generated during the experimentation were tested under standard conditions in the laboratories of SITRA (South India Textile Research Association), a research organisation based in Coimbatore, India by their technicians. Some fibre and yarn tests were carried out in the spinning mill, and for these tests the samples were conditioned as per the recommended procedures.

2.3 *Testing of Fibres*

2.3.1 Testing of Fibre Physical Properties

The physical properties of fibres like length, fineness, strength and elongation can be tested in several ways. The 'High Volume Instrument' (HVI) and the 'Advanced Fibre Information System' (AFIS) manufactured by Zellweger Uster have become quite popular for measuring these fibre characteristics. HVI systems are designed to measure large quantities of bale cotton samples within a minimum time frame. Typical HVI measurements include: micronaire, fibrogram length and length uniformity, 1/8-inch gauge length bundle tenacity, reflectance and yellowness on Hunter's scale as well as optical trash particle counts and trash area. The HVI system from Zellweger Uster uses the bundle test rather than single fibre test to establish the property and variability values.

2.3.1.1 Operation principles of the High Volume Instrument (HVI) [81]

The instrument makes use of a tuft of 'truncated fibres' or 'beards' prepared by a Fibrosampler device. The Fibrosampler specimen (in the form of a 'beard' of fibres) is held in a comb and the fibres are photo-electrically scanned from the base to tip; the amount of light passing through the beard is used as an indicator of the number of fibres that extend at various distances from the comb [58]. The fibres are placed on the comb in such a manner that they are caught at random points along their lengths (as they are held in a roller nip, Figure 2.1). The output displays the amount and the length data in the form of a fibrogram (Figure 2.2). The fibrogram is the curve representing the length distribution of the fibres sensed by the scanning of the fibre beard. The tapered beard is also used to measure the fibre strength and elongation. The maximum tensile force required to break the fibre tuft held between two clamps is measured and the path traversed by the moving clamp gives the fibre elongation. The fineness of the fibres is measured using the 'airflow' method, while the fibre colour is measured by a Colorimeter.

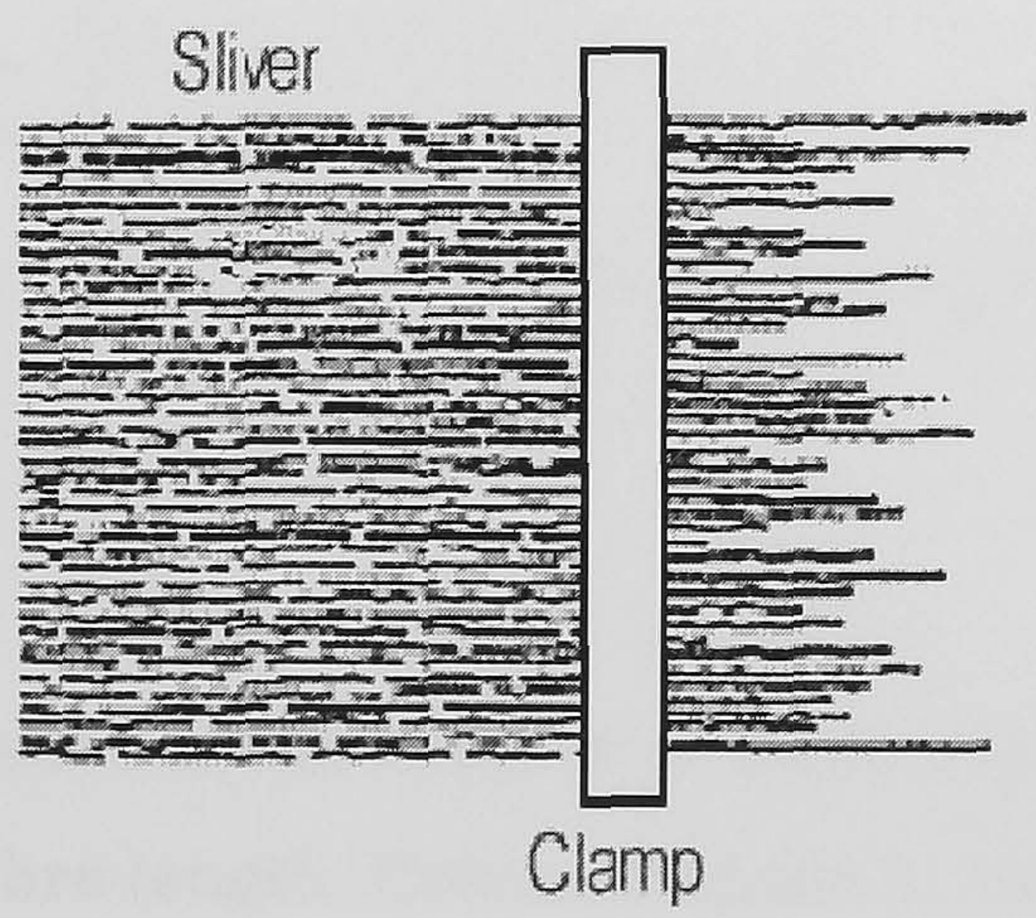


Figure 2.1: Sliver as clamped in a roller nip

I. Length and length uniformity

Length and length uniformity are two of the most important cotton fibre properties. Without sufficient fibre length it is not possible to spin a yarn and an even distribution of fibre length is a prerequisite to produce yarns at a high level of production efficiency. Fibre length has a substantial impact on yarn evenness, yarn strength, and spinnability and in fact, it accounts for over 40% of the variation in yarn strength [81].

The 2.5% and 50% span lengths are respectively the distances up to which 2.5% and 50% of the fibres caught in the sample holding comb are found to extend. The uniformity ratio is calculated by dividing the 50% span length by the 2.5% span length as derived from the Fibrogram. Typically, a higher uniformity ratio is needed for the ring spinning of a finer count yarn, and cottons with lower values can be used successfully in the rotor spinning of coarser count yarns.

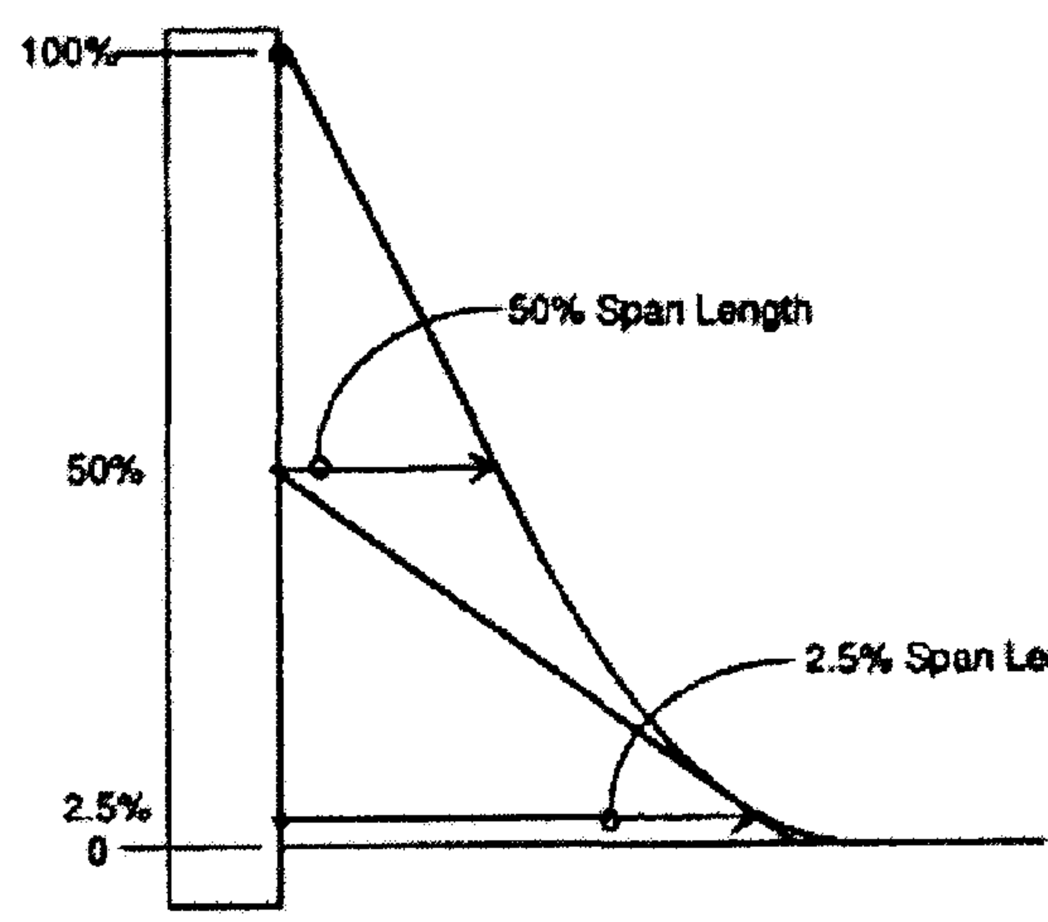


Figure 2.2: Fibrogram and Span Length [81]

II. Short Fibre Content

The short fibre content describes the amount of short fibres within a sample that are below half an inch in fibre length. Conventionally it used to be those fibres that are less than half the effective length (as measured from Baer Sorter diagram) [82]. Short fibres are considered waste material, as they do not contribute to yarn strength while causing production and quality problems in the spinning process.

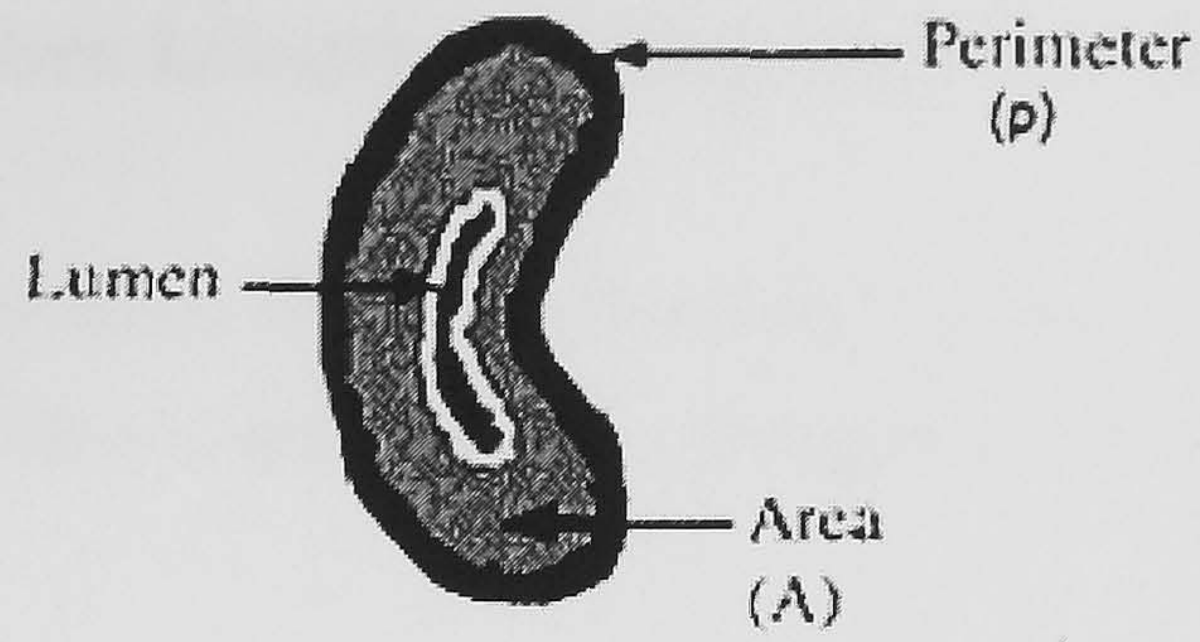
III. Strength and Elongation

Cotton fibres need to have a certain amount of strength to withstand the strain they undergo during the opening, cleaning, and spinning processes. Most importantly fibre strength and elongation are directly correlated to yarn strength and elongation. Strength is expressed in terms of breaking strength in g/ tex, while elongation is expressed as a percentage of the initial length.

IV. Micronaire and Maturity

In order to achieve a certain yarn count, a specific number of fibres are required per cross-section. The micronaire value, along with the fibre length, determines to a large extent what yarn can be spun from the cotton. Finer (low micronaire) fibres may cause neps in the yarn or fabric. Micronaire in combination with maturity has a strong effect on the dyeing ability of the yarn or fabric.

Cotton fineness can be defined in various ways: perimeter, apparent diameter, area of cross section, mass per unit length, or surface area. Gravimetric fineness can be expressed as the mass per unit length of a fibre. Biological fineness is either the perimeter of the fibre cross-section or the diameter, if the section is assumed to be round. To define "true" cotton fineness, both perimeter (or preferably total surface area) and cell wall thickness (or total volume of cellulose) must be known (Figure 2.3). Surface area can be expressed as area per unit volume (or specific surface) and can be estimated with an airflow instrument. The micronaire tester used widely for testing fineness consists of an air gauge to measure airflow through a cotton sample of specified weight, placed in a chamber of fixed dimensions. The rate of airflow through this plug is governed by intrinsic fineness and maturity. Instrument readings were assumed to indicate gravimetric fineness in mg/in, but were later understood to show that the scale actually represented the fibre surface area [81].



$$\varnothing \text{ [Degree of Thickening]} = \frac{4\pi A}{p^2}$$

Figure 2.3: Measurement of Cotton fibre fineness

V. Colour and Trash [81]

For several years, before the arrival of HVI, cotton colour was strictly determined by visual classification and given a "grade". Light spots or yellow cotton mixed with brighter cotton can result in dye imperfections known as barré. HVI measures brightness expressed in percent reflectance (% Rd) and the yellowness (+b) of cotton fibres. This information can be used to reduce problems related to uneven dye uptake, to confirm or establish the grade of cotton purchased, to control warehouse categories for colour grade and to establish colour control for bale selection.

The amount and size of trash within a bale of cotton also influences its value. Trash or foreign matter constitutes seed coat fragments or motes, leaf and stalk residues, sand, jute or polypropylene remnants used in packing etc. The trash content is found to vary largely between different varieties of cotton depending on cultivation conditions and harvesting methods, ginning method and the amount of post ginning cleaning. To spin high quality yarn at high production rates, it is desirable to select cottons with greater propensity to cleaning, rather than just using gravimetric determination of the degree of cotton contamination [56].

2.3.2 Testing of Fibre Length and Nep content using AFIS

The USTER AFIS (Advanced Fibre Information System) is a versatile laboratory instrument for single fibre testing and is designed as a modular system to suit specific requirements:

- Module N determines nep count, nep classification and nep size.
- Module L&M measures fiber length and maturity.
- Module T determines the number and size of particles of foreign matter, dust and trash.

A schematic of the instrument is shown in Figure 2.4.

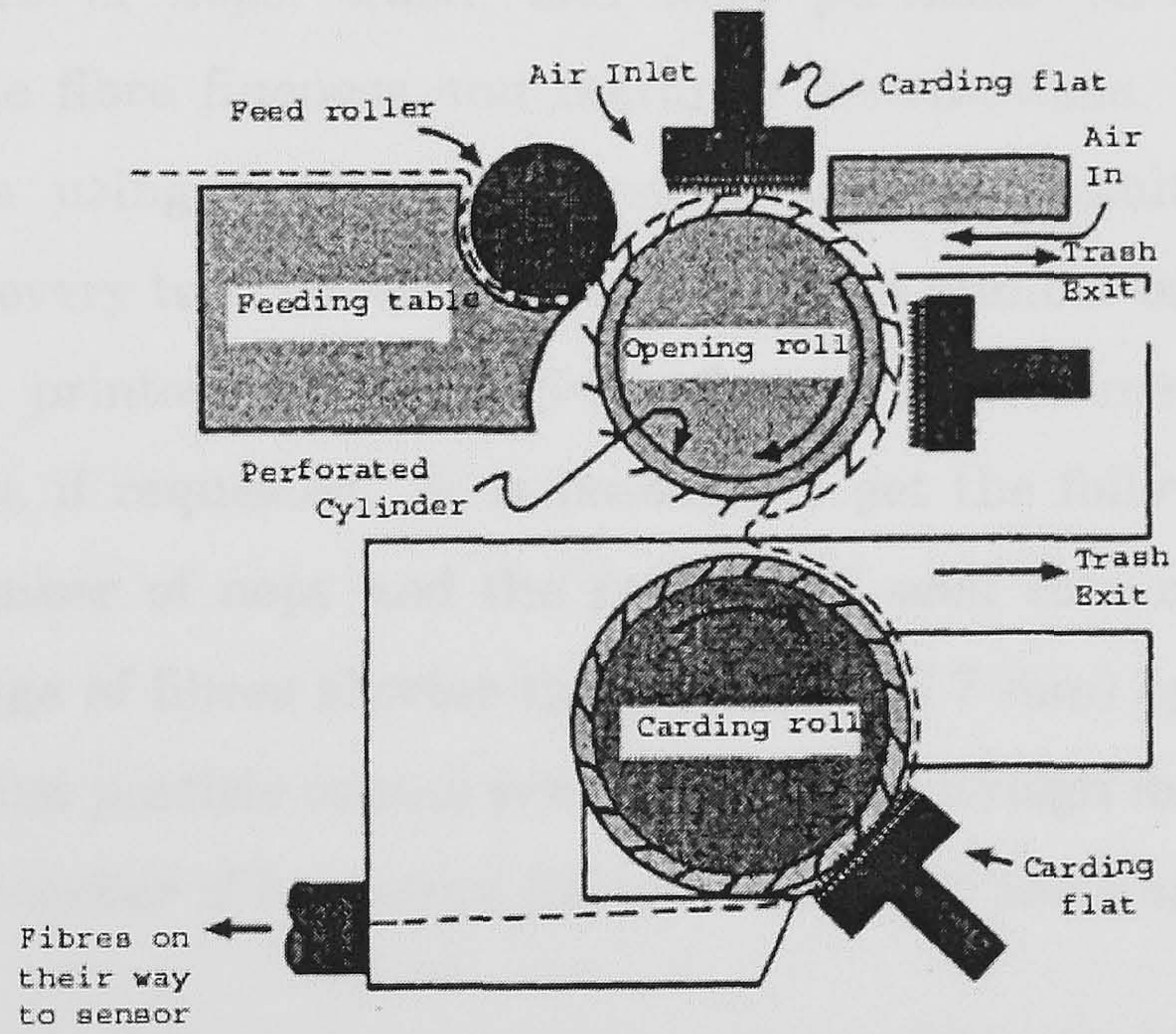


Figure 2.4 – Uster AFIS – Principle of fibre separation [83]

The AFIS system is fed with a sliver of fixed length formed from a weighed bundle of fibres. This sliver strand is drawn into the instrument by a feed roller, which feeds it to a pair of pin-type opening rollers, partially surrounded by carding segments that individualises the fibres and separate non-fibrous components. This unit is called a 'Fibre Individualiser'. The fibre individualiser unit utilises the principle of aeromechanical separation to extract trash particles, large seed coat fragments, and other types of foreign matter from the original fibre specimen [83].

While the foreign matter is conveyed through the trash channel, individual fibres, neps, and small seed coat fragments (seed coat neps) pass through the fibre channel. Electro-optical sensors are installed in both the trash and the fibre channel and advanced signal processing technology is applied to identify and characterize several thousand individual cotton fibers, fiber entanglements, and foreign matter. As a single trash particle or fibre passes through a beam, the light is scattered in relation to the visible area of the particle or fibre. The change in light is detected, generating voltages, which translate into characteristic waveforms as shown in Figure 2.5 (Page 74). These waveforms are analysed to produce statistical results.

The AFIS system provides information on the frequency distribution of single fibre length and the size of neps, trash, and dust particles. AFIS also provides assessment of single fibre fineness and maturity distributions. Operation of the instrument is done using a computer system and the results are displayed automatically after every test. On completion of a given number of repeat tests, the system will give a printout of the individual results, the mean result and a summary histogram, if requested. It is possible to get the following information from AFIS: the number of neps and the number of seed coat neps per gram of cotton; the percentage of fibres shorter than ½ inch (12.7 mm) by number and by weight; trash and dust particle counts per gram; visible foreign matter (VFM) and, information on the number of immature fibres, fibre count and fibre maturity.

The AFIS system uses a sample weight between 0.4 to 0.6 g. Modern AFIS systems automatically load samples, relieving the need for the continuous presence of a laboratory technician.

a) Measurement of Neps:

The nep module in the AFIS is a separate module from the length and diameter module. A nep is differentiated from a fibre by the shape of the waveform – a nep gives a single peak waveform as shown in Figure 2.5. The neps counted within the sample weight of 0.4 –0.6 g are reported as neps/gram. AFIS also displays the information on average nep diameter and also nep size distribution in the form of a histogram.

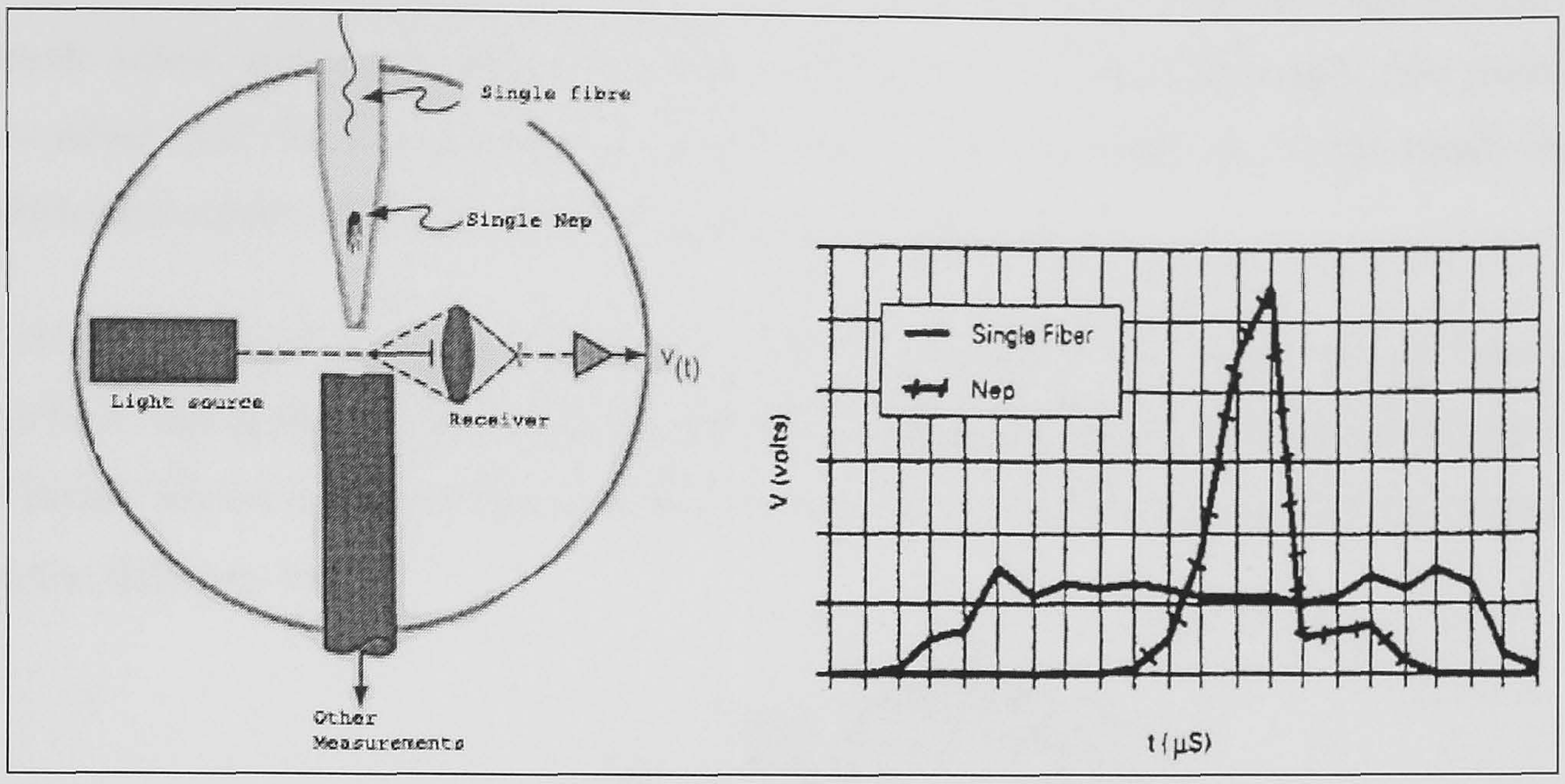


Figure 2.5- Waveforms for fibre and Nep [83]

b) Measurement of fibre length and diameter:

The L & D module uses the same sensor as that used for fibre nep measurement. AFIS counts only straight fibres determined from the waveform. If a fibre is hooked at one end, the diameter will be double and AFIS will ignore the length of this fibre. Length is determined from the time taken for a fibre to pass through the light beam and the diameter is determined by measuring the amount of light scattered. The corresponding waveform is unique and used for fibre diameter determination.

2.3.3 Trash Tests - Shirley Analyser [82]

The Shirley Analyser operates on the principle of 'buoyancy separation' by the use of air currents. A schematic of the analyser is shown in Figure 2.6. The cotton sample whose trash content needs to be determined is placed on the feed table of the Shirley Analyser. It is presented to a fast rotating licker-in, by a feed roller-feed plate arrangement. The licker-in opens the sample to near individual fibre state. Due to the strong centrifugal forces, both the cotton fibres and the trash tend to travel tangentially outwards and enter the air stream. There is a 'streamer plate', which is specially shaped to permit the air currents set up by the motion of the licker-in to join the general air stream. The separation of the cotton and the trash takes place as the two travel with the air stream through the settling chamber and the heavy trash particles tend to fall straight in to the trash tray, while the cotton fibres are controlled by the air stream.

Cotton and light dust are carried out of the chamber and drawn on to the cage surface, the dust being sucked through the cage perforations. The cotton forms into a layer, which is moved forward by the rotating perforated drum and delivered in to the delivery box.

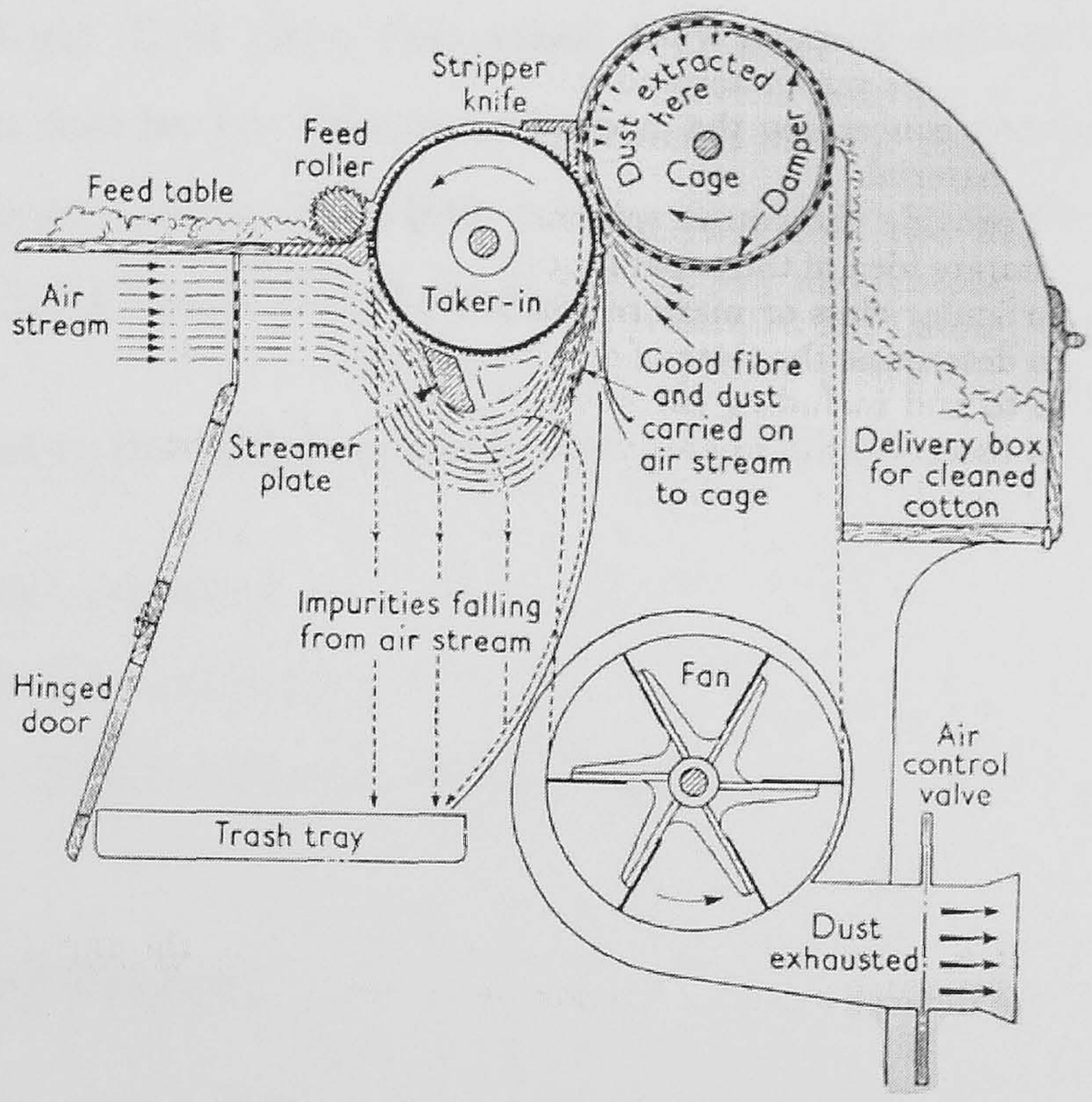


Figure 2.6 – Shirley Analyser [82]

Trash Determination:

The trash content in the cotton was estimated using British Standards BS 2889: 1967 and the procedure adopted is described:

The cleaning efficiency of the carding machine is calculated as follows:

$$\text{Cleaning efficiency (\%)} = \frac{(\text{Trash in Lap} - \text{Trash in sliver})}{\text{Trash in Lap}} \times 100$$

A sample of 100g in weight is taken and fed through the analyser. The lint collected from the lint box (L1) is made to pass through the analyser for the second time. The lint yield (L2) is collected and kept separately.

The lint in the trash box is taken out and fed through the analyser. This results in lint L3. The lint L3 is again fed through the analyser to get lint L4. This lint L4 is added to the previously collected lint L2 and their combined weight is calculated.

The trash in the trash tray is collected and weighed (called T4 because of the four passages of the lint). Lint from this trash is collected and passed through the analyser. This lint will be L5. Whatever lint is found in the trash tray again is fed through the analyser again. The lint produced in the process is collected, and classified as L6. Lint L5 and L6 are weighed together.

Total trash content in the cotton is computed in the following way.

Trash content = T4 – (L5+L6)
Lint content = (L2+L4) + (L5+L6)
Cage Loss = 100 – (Trash content + Lint content)

2.4 Testing of Yarns

2.4.1 Evenness testing of Yarns

An Uster Evenness Tester 4 was used for the yarn evenness measurements. This is one of the modern and widely used testers used to measure the mass variations of yarns, rovings and slivers made from staple fibers. Based on this measurement, quality-determining characteristics, such as the coefficient of variation (CV) or imperfections are calculated.

Besides providing this basic function, the Uster Tester 4 can also [81]:

- compare the measurement values with pre-determined standards.
- detect and interpret periodic faults.
- automatically compare and produce graphic representation of the measured quality parameters.
- prepare long-term reports.
- provide simulated yarn boards, woven and knitted fabrics.

With the optional sensors of the tester, it is possible to simultaneously measure evenness, imperfections, hairiness, number of seed-coat fragments, yarn diameter, yarn density and yarn structure. Graphic representations such as spectrogram, histogram and variance-length curve facilitate the interpretation of data [81].

The Uster evenness tester uses parallel plate air capacitors to measure the mass variability. When a non-conducting material such as a sliver or a yarn is passed through two parallel plate capacitors, changes occur in the capacitance values that are proportional to the mass of the material present. This short-term variability in linear density (yarn length equal to the length of the capacitors) is used to measure the evenness of the material [82]. The capacitors that are used for measuring yarn evenness are 8 mm long (longer for sliver and roving) and the tester electronically determines the coefficient of variation of the weights of 8 mm lengths along the entire test length (generally 400 metres or 1000 metres in case of yarn). The mean deviation or CV% is a common term used to express the evenness of the yarn and obviously the greater the CV, the higher is the unevenness of the material.

The Uster Evenness Tester 4 consists of 4 basic units.

1. A 'Measuring Unit' that houses the separate measuring slots for the sliver, roving and yarn.
2. A 'Processor Unit' that is basically a micro-computer that continually monitors, records and evaluates the input from the measuring unit to compute the unevenness CV%, imperfections etc.
3. A 'Visual Display Unit' that displays all the test and results information

4. A printer to print the results on to paper.

The yarn evenness testing involves a more detailed analysis of the faults or imperfections. The measuring unit measures thin places, thick places, neps, and the evenness of the yarn. Standard measuring conditions for imperfections have been established by Uster and are defined as follows.

i) Thin places (- 50%):

These are faults having a cross-section 50 percent less than the average value. The thin places (-50%) are normally measured at a sensitivity setting of –50%, though there are other non-standard sensitivity settings that are available such as – 30% and – 40%.

ii) Thick Places (+50%):

These are faults having a cross-section of 50 percent more than the average value. As with the thin places settings, a sensitivity setting of + 50% is the standard, while other sensitivity settings like + 35% are possible.

iii) Neps (+200%):

Neps are faults that have a fault length of 1 mm and having a cross-section of 200 percent of the average value. A setting of +200% is the standard setting for ring spun yarns, but for rotor yarns a +280% setting is used.

It is possible to count smaller faults or ignore faults by altering the sensitivity settings. In some of the experiments, the number of thin places (-50%) was less than 1 per kilometre and in those cases, the non-standard -30% setting was used for comparison.

The standard testing speed of 400 metres per minute was used and the test duration was 2.5 minutes per test. Ten tests were carried out per sample to compute the unevenness and imperfections as recommended by Uster [80].

2.4.2 Testing of Yarn Infrequent Faults:

Yarn infrequent faults as the name implies are those faults that occur rarely over thousands of metres of yarn tested. Therefore, to test the yarn for such faults, test lengths of 100 kilometres are used so that a good estimate of yarn faults can be obtained.

The testing system that was used for measuring these seldom-occurring faults was the Uster Classimat 3 tester. This measuring system works on the same capacitance principle as the evenness tester. It detects the faults and classifies them according to their length and mass. The thin and thick places counted by the system are classified in to a matrix of 23 classes as illustrated in Figure 2.7.

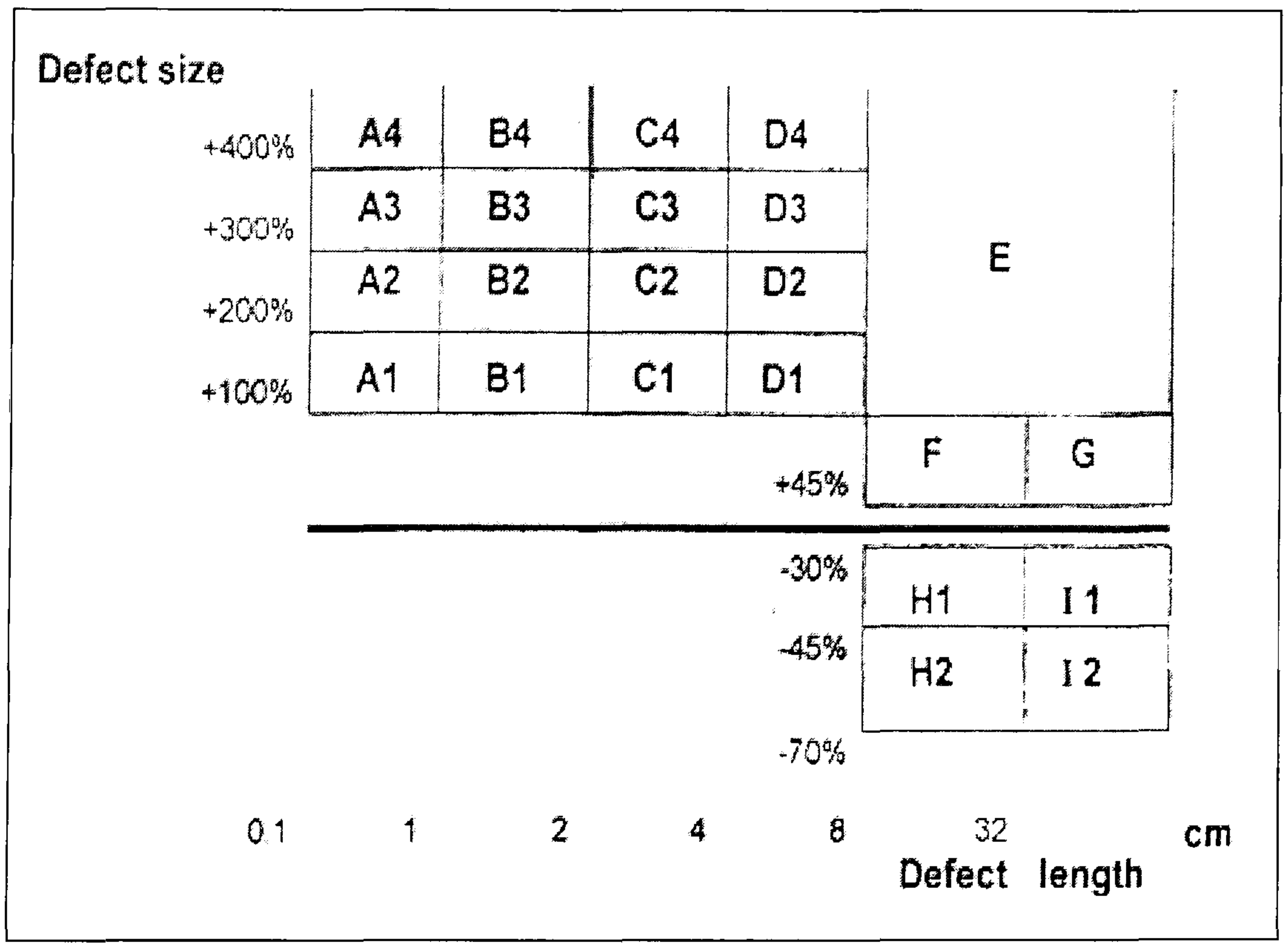


Figure 2.7 - Classimat matrix for yarn faults [84]

A letter and a number identify each type of fault. The letter refers to the length of the fault and the number indicates the dimensional size of the fault. Faults classified from A to G indicate the thick faults, while the letter H and I represent thin faults. These faults can be further divided into

1. short thick faults (A1+B1+C1+D1) [1]
2. long thick faults (E+F+G) and
3. long thin faults (H1+I1)

The measuring installation consists of a small winding unit (cone or cheese winding) having six winding positions and a measuring unit positioned in between two tension discs on each of the winding positions.

The Classimat faults include slubs, spun-in fly, loose fly, hard piecings, spinners doubles, trash and seed coat fragments, and drafting faults [84]. These faults are to be avoided or reduced because they cause breaks during post spinning operations like winding, warping, weaving or knitting and also affect the aesthetic appeal of the fabrics. For example, in applications such as knitting, faults that are large in cross-section (say + 250%) can cause needle breakage. Therefore the spinning mills clear some of the faults depending on the intended end use by using yarn clearers during the winding process.

It is recommended that 5 tests of 100 kilometres should be carried out for measuring the infrequent faults in a production environment [84]. For the purpose of this investigation, it was not practical to spin such a large quantity of yarn. Moreover, since faults that were generated during carding (like A faults) occur in large numbers in the yarn, the testing was scaled down to a single test with a minimum of 100 kilometres. After all other tests and knitted samples had been made, Classimat tests were carried out on the remaining yarn. The test results were converted to the nominal length of 100 kilometres.

2.4.3 Measurement of Yarn Count and Lea Strength:

The skein (lea) count and strength measurements (to compute Count Strength Product) were carried out on automated testers both in the spinning mill and at SITRA. The lea is produced on a wrap reel by wrapping 120 yards of yarn on a 1.5-yard girth reel. The wrap reel is a simple instrument consisting of a motor driven reel, yarn package creel, a yarn guide, and a length indicator. As soon as the set length is reached, the reel comes to a stop and the lea or skein can be taken out.

Modern automated testers for computing Count-Strength Product consist of a fine balance and a skein strength tester that are combined in such a way that the output of the two instruments is fed into a single processor. The processor calculates the count strength product for each individual sample and also calculates the mean and the coefficient of variation for a group of results.

The lea strength tester works on the principle of Constant Rate of Extension (CRE). The calculation of the Count Strength Product (CSP) is given below.

$$\text{CSP} = \text{Lea strength in pounds} \times \text{English Yarn count (Ne)}$$

As the yarn counts vary from the nominal count spun, corrections to the CSP were made using the following formula.

$$\text{Corrected CSP} = \sqrt{\frac{(\text{Actual CSP})^2 \times \text{Actual yarn count}}{\text{Nominal yarn count}}}$$

This measurement of lea strength is a rapid test and so is very useful in the production environment. However, it is not error proof as there could be tension variation among the threads within a lea or in the way the lea is placed over the jaw of the tester by the operator. Although, it is a good way of getting some approximate estimates, the single yarn strength test is considered the industry standard, as it is an automated test with the least likelihood of incurring operator error.

2.4.4 Single Yarn Strength Testing:

Single yarn strength testing was carried out on Premier Tensomaxx 7000 tester manufactured by Premier Polytronics. This machine is designed to carry out a series of tests automatically.

This instrument works on the principle of 'constant rate of extension' (CRE). In the CRE principle, the moving jaw of the tester is displaced at a uniform rate. As a result, the specimen held between the stationary and the moving clamp is extended at a constant distance per unit time. CRE single-end testing at 5-m/min clamp speed is the most widely accepted practice in the international textile industry [80]. The force required to break the specimen is measured and also the extension at the break is recorded.

The system is fully computerised and as with the evenness tester the specimen details are inputted to the data processor via a keyboard. The details inputted include type of material (cotton or synthetic), the linear density (Ne or tex), pre-tensioning weight, number of packages, number of tests per package etc. The required number of packages are creeled into the automatic feed unit incorporated in the testing unit before commencing the tests.

The instrument provides a printout that presents a graphical representation of force and elongation, individual values of force, elongation, work and tenacity. By expressing the breaking strength in terms of tenacity (g /tex), different specimens of varying fineness can also be compared.

For the experiments, 50 tests were carried out (10 per package) at a testing speed of 5000 mm per min. The length of the specimen used in each test was 500 mm with a pre-tension of 0.5 g/tex.

2.4.5 Measurement of Yarn Hairiness:

The hairiness of the spun yarn is today considered to be as important as yarn evenness and strength, as how the yarn behaves and performs in further processes is influenced by the hairiness of the yarn. Hairy yarns, though giving the resultant fabric a fuller appearance, can also lead to increased pilling on the fabric surface that can ruin the fabric appearance. Hairiness also increases the frictional properties of the yarn and thereby could result in higher yarn breaks during the warping, sizing, weaving or knitting processes.

The control of hairiness is therefore one of the important functions of a quality control department in a spinning mill. The hairiness can be controlled by choosing the right raw material mix, the right components on a spinning machine (ring and traveller, thread guides, aprons etc) and by maintaining them [85].

Yarn hairiness was measured using a Zweigle Hairiness Tester G 565 at SITRA laboratories. This tester was originally developed at Institute for Textile Technology in Denkendorf (ITV). This tester works on optical measurement of the hairiness profile of a yarn. Any fibre protruding above the surface of the yarn is counted by projecting a fibre shadow onto phototransistors [85]. The Zweigle G 565 tester simultaneously counts the number of hairs in 12 length zones ranging from 1 to 25 mm (1,2,3,4,6,8,10,12,15,18,21 and 25mm). The testing speed is kept constant at 50 m /minute and a test length is set between 1-9999 metres. The output of the hairiness tester gives the effective number of hairs in each length zone, Hairiness Index and S3 value (mean number of hairs longer than 3 mm per metre).

The advantage claimed by the Zweigle in this test system is that the surface of the passing yarn does not change due to the easy running guide rolls. Zweigle also claims that the higher testing speeds used in other instruments (such as Uster Evenness Testers with hairiness module) tend to distort the hairiness results due to higher air resistance which results in the fibres sticking to the yarn core [85].

For the experimental samples, ten tests were carried out for every sample. The test length was 100 metres per test. All the testing was carried out at SITRA's testing facilities by their technician.

2.5 Tracer Fibre Configuration Studies

In order to study the fibre arrangements in the yarn, a suitable method was required that would allow an individual fibre to be isolated from the other fibres say in a sliver or a yarn so that their configuration could be recorded. A technique that was pioneered by Morton and Summers [64] has become the basis from which other techniques were subsequently developed.

The method for tracer fibre analysis used in the present work was similar to the one used by several other workers previously [65,67,69,74]. This work involved the study of fibre configuration in yarns in order to ascertain whether it is influenced by the licker-in design as claimed by Rimmer [46].

As mentioned in Chapter 1, in the technique used by Morton and Summers, a small quantity of black dyed fibres was mixed into the bulk of the material prior to carding. The slivers were immersed in a solution, which had the same refractive index as the material. When the yarn is viewed through a microscope, the undyed material appears transparent, leaving the dyed fibres clearly visible.

The technique used in this work was a modified version of the Morton and Summers technique. Black tracer fibres (0.05%) made from the respective cotton varieties were introduced into the mix. After a thorough mixing, the material was processed through the blow-room to spinning and spun into yarns of the required linear density.

2.5.1 Apparatus used for Tracer Analysis

The special experimental rig used for the fibre configuration studies is shown in Figure 2.8. The rig has a glass trough situated between a yarn tension guide and a spool on an aluminium plate. This rig was fitted with an Olympus CX-41 compound microscope having a trinocular port for attachment of a camera. Tracer images were captured with a COHU 4910 monochrome CCD camera at a magnification of 100 times and recorded on a computer with a frame grabber and software to operate the frame grabber.

The rig has a special arrangement to capture the images of the orthogonal projections on two planes XY and XZ (front view and side view). The arrangement shown in Fig 2 comprises a mirror, inclined at 45 degrees, positioned such that a reflected image of the yarn can be observed under the microscope. This arrangement enables a study of the 3-dimensional fibre disposition within the yarn.

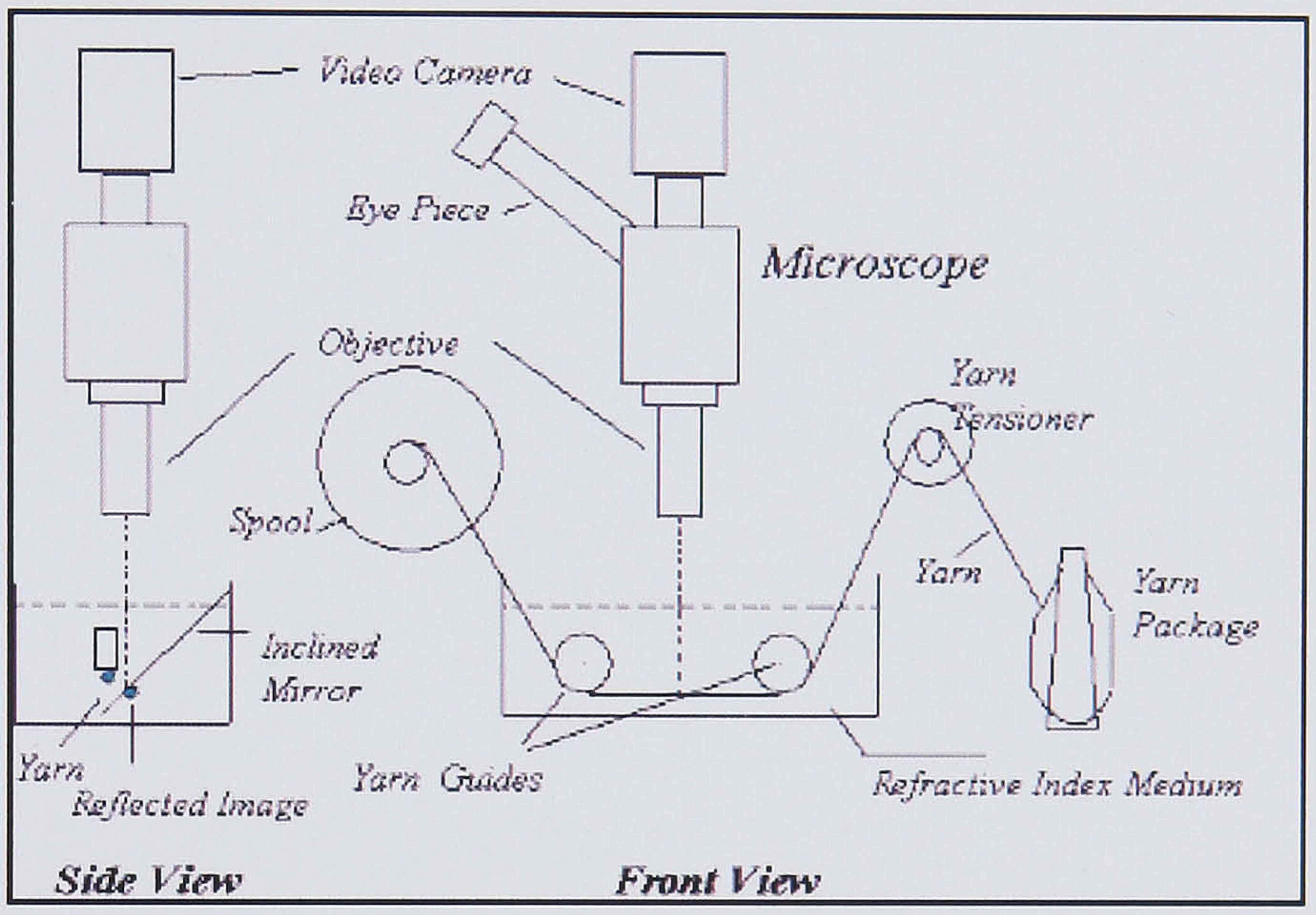


Figure 2.8 – Rig used for fibre configuration studies

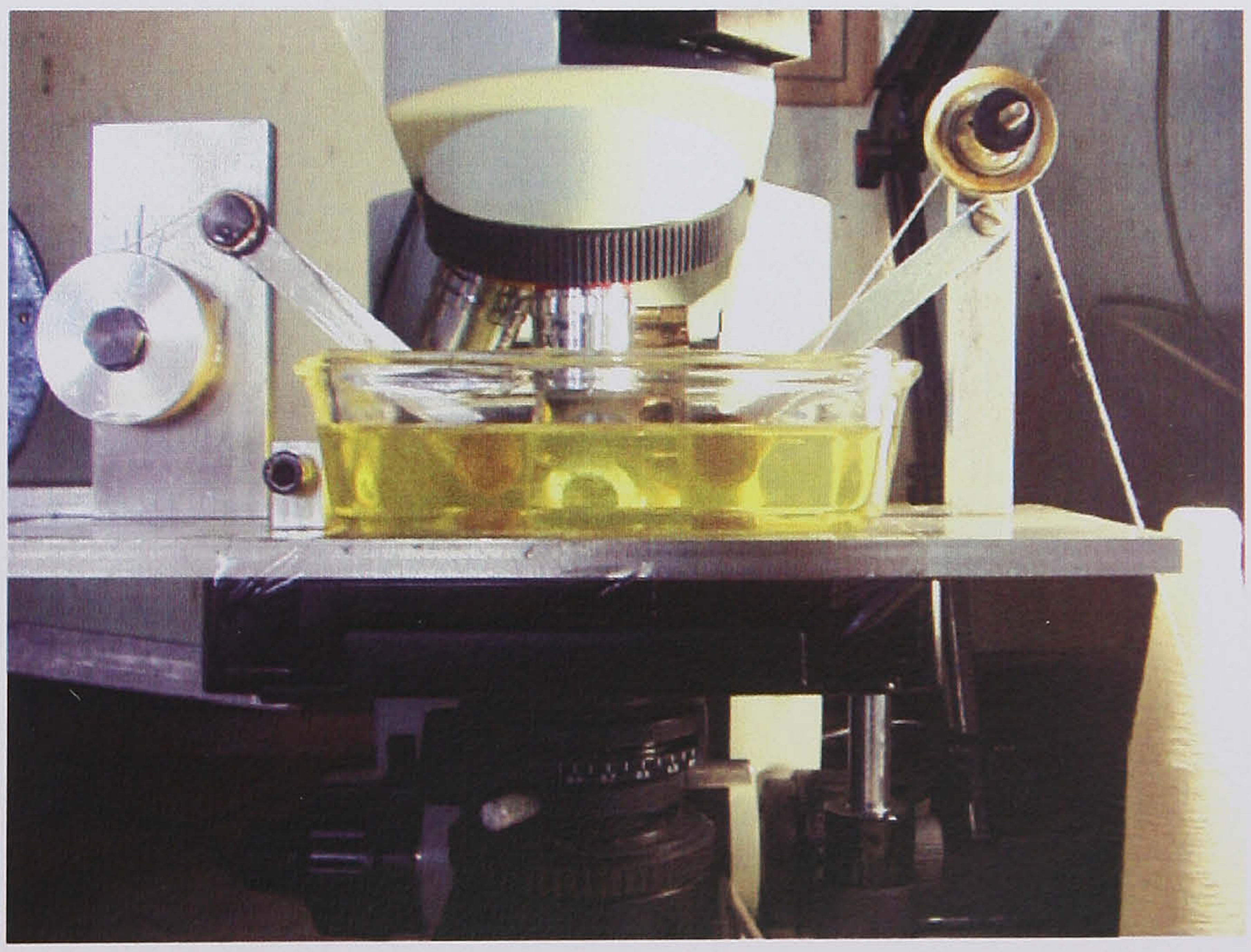


Figure 2.9 – A closer look at the test rig

2.5.2 Refractive Index Medium

To optically isolate the tracer fibres, the yarn was immersed in a liquid medium whose refractive index was close to that of cotton. Cotton has a refractive index of about 1.557 [64]. A study was carried out with different liquids having refractive indices close to that of cotton. The liquids that were experimented with are given in Table 2.1.

Table 2.1: Refractive Indices of the media used for configuration study

Medium	Refractive Index
Glycerine	1.456
Cedarwood oil	1.505
Methyl Salicylate	1.546
Tricresyl Phosphate	1.556

Experiments were conducted with the above media and their mixtures. The media used by many research workers at the University of Leeds and in other institutions [65,67,69,74] to study the cotton was either methyl salicylate or tricresyl phosphate. However, both the media were found to give unsatisfactory images, especially for the coarser yarn produced during the experiments, so a 50:50 mixture of tricresyl phosphate and cedarwood oil (mixture $\eta D= 1.531$) was tried and found to give the best results in terms of tracer visibility. The mixture was also found to be stable and could be reused for several times. However, the mixture generates fumes that are toxic in nature and hence the microscope along with the test rig was placed in a fume cupboard (Figure 2.10).

In the coarse yarn produced during the quality trials (29.5 tex), parts of the tracer fibres could not be seen clearly, probably due to the greater number of fibres in the yarn cross-section. Following several tests, it was concluded that longer immersion times (up to 4 hours) were required to achieve a good clarity of tracer image. In order to achieve this, the yarn was passed slowly through the refractive index medium (to enable the yarn to pickup the liquid) and wound on to a spool. The wet yarn on the spool was left overnight to saturate and unwound from the spool the next day through the medium and tracer images were captured.

Figure 2.10 – Complete tracer analysis arrangement showing fume cupboard, computer and connections

2.5.3 Camera

Four different types of cameras were tried. They include a monochrome CCD camera, a colour CCD camera, a Digital SLR camera and a normal digital camera. The best image quality was obtained using the COHU 4910 monochrome CCD camera, having a resolution of 580 x 350 TV lines. The camera has a 1/2-inch image sensor that produces an analogue output, which is proportional to the amount of light incident on the camera. The analogue signal was digitised by connecting the analogue output to a computer fitted with a frame grabber and its associated software. When a tracer fibre came into view, a snap shot was taken of the sample from the computer and saved as a file. The camera has an electronic shutter speed control, so the shutter speed can be varied from 1/50 sec to 1/10,000 sec in 8 steps. In addition it has provision for adjustment of the Gamma value, so the image brightness / contrast can be enhanced. For this work, a shutter speed of 1/50 sec and a gamma value of 1 were found to be appropriate.

2.5.4 Lighting

Lighting was another critical area for tracer fibre observation under the microscope and two types of illumination were tried. One was a 150 W fibre optic light source and the other was an ordinary table lamp (11 W fluorescent lamp). The white light of the table lamp yielded clearer and crisper images than the fibre optic and hence the latter was used. Figure 2.11 shows the arrangement of the lighting used for the study.

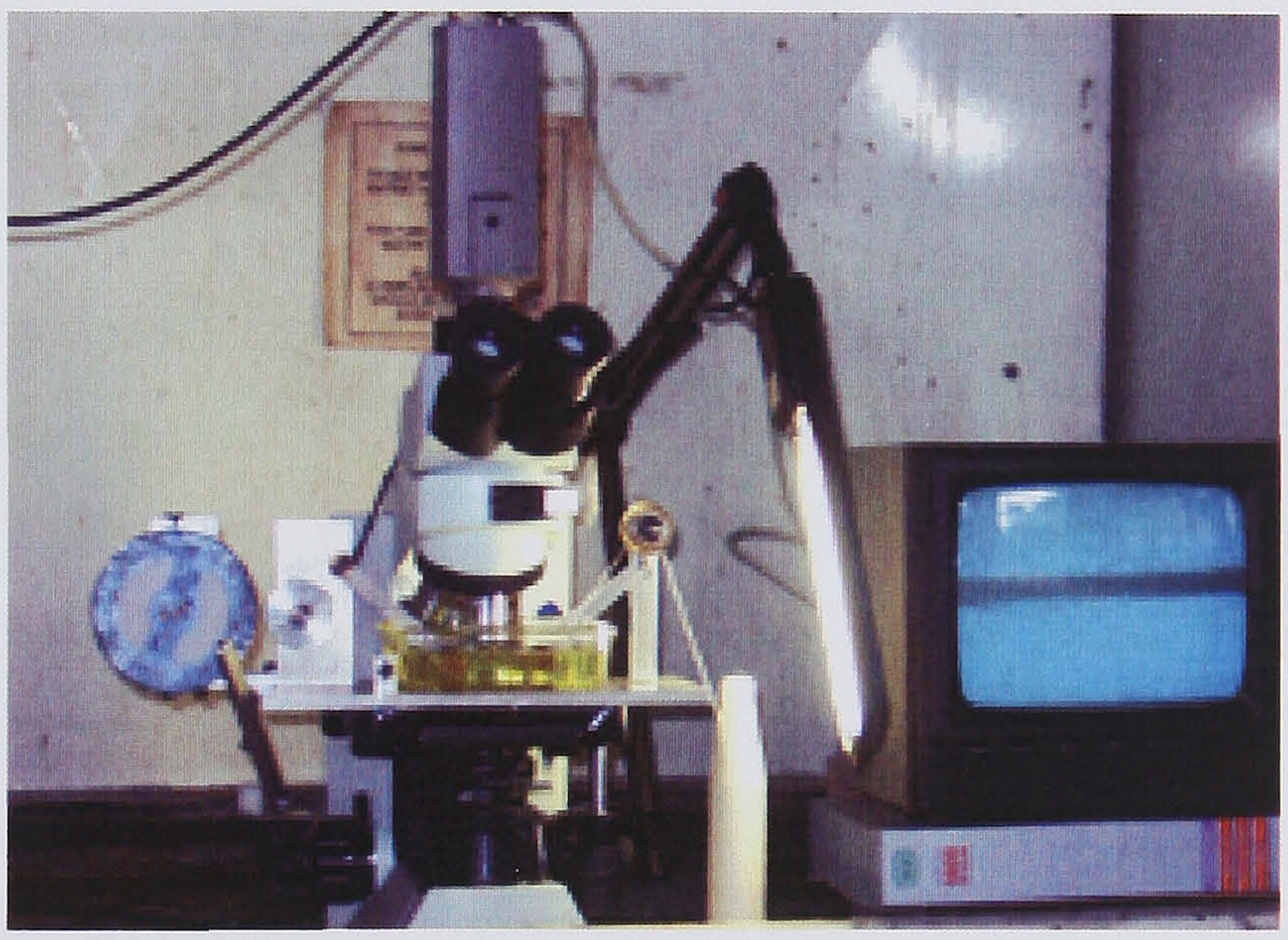


Figure 2.11 – The arrangement of lighting used for the tracer study

2.5.5 Sample size

A suitable sample size had to be chosen for the study. Analysis of the literature revealed that many researchers used between 10 and 25 fibres for tracer fibre analysis in yarns. Table 2.2 gives the sample size used by some of the researchers for tracer fibre analysis in yarns.

Table 2.2- Sample sizes used by different researchers

Author	Sample size (No. of fibres)
W.E.Morton [87]	10
Hearle and Gupta [88]	20
Huh *et al.* [89]	10
Huh *et al* [90]	15
Salhotra *et al* [91]	25
Gupta *et al* [92]	15
Alagah *et al* [93]	25
Rimmer [46]	25

It was decided to use a sample size of 25 fibres for this work. On average, 9 to 10 captured fibre image sections constitute one fibre length. Since the yarns were observed from two directions (XY and XZ directions), over 6000 images (fibre sections) were captured and joined together, with each image representing a fibre section of approximately 2.7 mm. The images were captured in such a way that there was an overlap of about 10 % to ensure that they could be joined together easily; to get the full tracer fibre image in the yarn. Adobe Photoshop software was used to join the fibre images, which were then highlighted using Paintshop Pro software to darken the tracer images and to extract only the tracer paths (Figures 2.9 and 2.10). The process is explained in more detail in section 2.9. Extracted tracer images were analysed using Image Pro Plus (Media Cybernetics, USA) software.

One hundred tracer fibres from every sample were also observed under the microscope for other aspects of fibre disposition such as fibre hooks, loops, kinks etc., which are discussed in detail in Chapter 4.

2.6 Fabric Test Procedures and Apparatus

2.6.1 Fabric Pilling Test

Pilling is a fabric-surface fault characterised by little 'pills' of entangled fibres clinging to the cloth surface [82]. These pills are formed by the rubbing action incurred during wear and washing. This rubbing action causes the entanglement of loose fibres that protrude from the fabric surface. Pilling is common in all woven or knitted fabrics made out of staple fibres.

Single jersey knitted fabrics were knitted from the yarns produced from every experiment. These fabrics were tested for the degree of pilling at SITRA using an ICI pilling box test method as per IS: 10971-84*. The method of test is as follows. A piece of fabric measuring 125 mm × 125 mm is sewn so as to be a firm fit when placed round a rubber tune 140 mm long, with a 31.5mm outside diameter and a thickness of 3.2 mm. The cut ends of the fabric are covered by PVC adhesive tape and four tubes are placed in a box (235 mm × 235 mm × 235 mm) lined with a 3.2 mm thick cork. The box is then rotated at 60 rev/min for 5 hrs. After this process, the extent of pilling is visually graded. Table 2.3 gives the pilling grades.

Table 2.3: Pilling grades

Pilling Grade	Degree of pilling
1	Very severe pilling
2	Distinct or severe pilling
3	Moderate pilling
4	Low pilling
5	No pilling

2.6.2 Knitted Fabric Regularity and Cleanliness

The knitted fabrics produced from the yarns were also assessed for their regularity and cleanliness. Appraisal of knitted fabric regularity and cleanliness is a difficult

* Indian Standards

exercise, as they cannot be measured numerically. Therefore, a method had to be devised to estimate the regularity and cleanliness of fabrics.

Samples of the knitted fabrics were cut to 50 cm by 50 cm and given a code letter A, B, C etc. by which they could be identified. The samples were hung next to each other in bright sunlight. There were six fabrics to be compared in this case. People with the necessary expertise working in SITRA were asked to assess the fabrics. Ten judges were asked to assess the fabric appearance by ranking from 1 (best) to 6 (worst). The fabrics were rated for cleanliness in the same way.

The method used to assess and rank the decision of the individual judges was based on the method used by Rimmer [46]. The assessment of the rankings was carried out as follows.

If all the judges were in complete agreement, the best fabric would have gained a 'rank total' of 10 points and the second best fabric 20 points and so on with the worst fabric gaining 60 points. The sum of all the rank totals would then be 210. If the judges had no ability to rank the fabrics, the ranking numbers would be at random and therefore the rank totals would be equal to one-sixth of the total of 210, i.e. equal to 35. Individual rank totals (of every sample) are subtracted from this value to get the difference 'd', this then squared to give d^2. The sum total of the squares of the differences gives the value 'S'. Table 2.4 gives an example of the calculation.

Table 2.4: Determination of the value 'S'*

Sample	Rank Total	Difference 'd' (35 - RT)	(Difference) ^{2} d^2
A	12	23	529
B	36	1	1
C	52	17	289
D	23	12	144
E	28	7	49
F	45	10	100
			1112 Sum of d^2= S

*S = Sum square of differences

The measure of the degree of agreement among the judges in the ranking of the fabrics is given by the coefficient of concordance. This can be calculated by the formula:

$$\text{Coefficient of concordance (W)} = \frac{S}{[m^2(n^3 - n)] / 12}$$

Where: S = the sum squares of the differences.
m = the number of judges.
n = the number of samples.

In this example,

$$W = \frac{1112}{[10^2\ (6^3 - 6)]\ /12} = 0.635$$

The value W can vary between 0 and 1, values near 0 indicating poor agreement and values approaching 1 indicating close agreement. In this example, we can say that the judges exhibited a fairly good agreement because of the higher value of coefficient of concordance.

2.7 Experiments with Single and Triple Licker-in Arrangements

Chapter 1 discussed in detail the different licker-in systems in use today. The most important of them are the single and triple licker-in systems. The triple licker-in system has been claimed to improve productivity over a single licker-in by 30% to 100% because of an improved opening in the licker-in zone [2, 39]. However, it has also been claimed that the triple licker-in adversely affects the fibre configurations in the card sliver and in the yarns [46]. Therefore in this work, to compare the performances of the single and triple licker-in arrangements it was decided to investigate the quality of yarns spun using the single and triple licker-in systems, to study the fibre configurations within the yarns and also to try to relate the results to the actual processes taking place within the licker-in zone using high-speed photography. The overall objective of this research is to reach a better understanding of the fibre dynamics within the licker-in zone and the dynamics that reflect on fibre, yarn and fabric quality.

It was decided to compare the carding performances of a single licker-in arrangement and a triple licker-in arrangement in a production environment. Part of the experimentation (related to quality trials) with the two licker-in arrangements was carried out in a production environment and the remaining part (high-speed photography experiments) was carried out in the carding laboratory of the University of Leeds. A production environment obviously means that the experiments needed to be conducted in a spinning mill. Since the University carding laboratory had a single licker-in Crosrol Mark IV carding machine for further experimentation using high-speed photography, it was decided to conduct the single licker-in experiments (and triple licker-in experiments after modification of the licker-in zone) on a Crosrol Mark V carding machine that was available in an Indian Spinning Mill. The Crosrol Mark V card is basically designed to use a single licker-in and was therefore modified to suit a triple licker-in unit for this work. The construction and installation of the triple licker-in unit used for this project is explained in the following section.

2.7.1 Construction and installation of triple licker-in in the spinning mill

Initially, it was attempted to attach the commercially available triple licker-in arrangement (DK 803 card triple licker-in shown in Figure 1.19, Chapter 1) to the Crosrol Mark V card in the spinning mill. Because of certain mechanical constraints, it was not possible to fit the commercial triple licker-in to the Crosrol carding machine. A new triple licker-in that was very similar to the DK 803 triple licker-in was therefore fabricated with suitable fixtures. A cross-section of the arrangement is shown in Figure 2.12. Figure 2.13 shows the licker-in rollers, which were fitted to the carding machine.

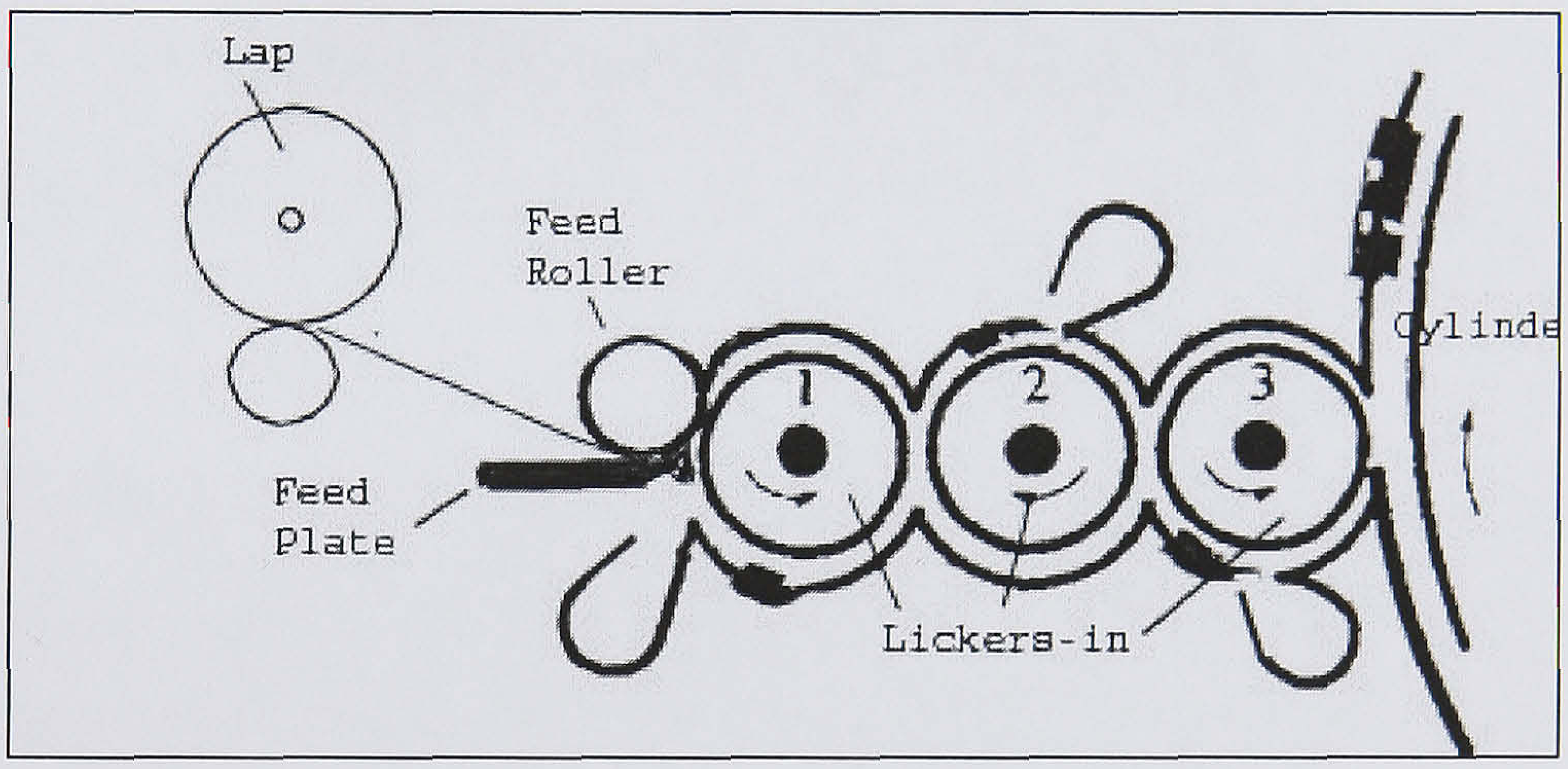


Figure 2.12: Schematic of the triple licker-in arrangement used for experiments

Figure 2.13 – Roller arrangement in triple licker-in unit on the card (without enclosures)

The licker-in rollers of the triple licker-in arrangement were manufactured to the same dimensions used in the DK 803 triple licker-in (172 mm) and were clothed with the same type of clothing recommended by Truetzschler for their DK 803 card. The under and over casings used were made of stainless steel material, which imparts a smooth finish. Care was taken to ensure that all the fibre contact areas were highly polished in order to ensure smooth flow of the material in the licker-in zone. In a similar manner to the original DK 803 design, an arrangement for the continuous suctioning of the waste was provided in the licker-in zone.

The triple licker-in arrangement was connected to the carding machine in place of the existing single licker-in. Though it was not an easy job to fit a triple licker-in to an existing carding machine, it was accomplished successfully with the help of mill technicians.

It should be noted that this triple licker-in arrangement used a conventional feeding arrangement (Figure 1.3, Chapter 1) and not the concurrent feeding arrangement (Figure 1.4, Chapter 1) used in the DK 803 card. The single licker-in arrangement in Crosrol Mark IV (and Mark V card) uses the conventional feeding arrangement. Therefore, in order to avoid introducing another variable in the comparison of the two licker-in arrangements, it was decided to retain the conventional feeding arrangement for the triple licker-in experiments as well.

Two different cotton varieties that had black tracer fibres in the mix were processed using the single and triple licker-in arrangements on the Crosrol Mark V card in the spinning mill. Therefore, the carding machine was not connected to the chute feeding system used for feeding the cards; instead a lap feeding arrangement with the required drive arrangements was provided. Figure 2.14 shows the arrangement of the lap feed on the carding machine.

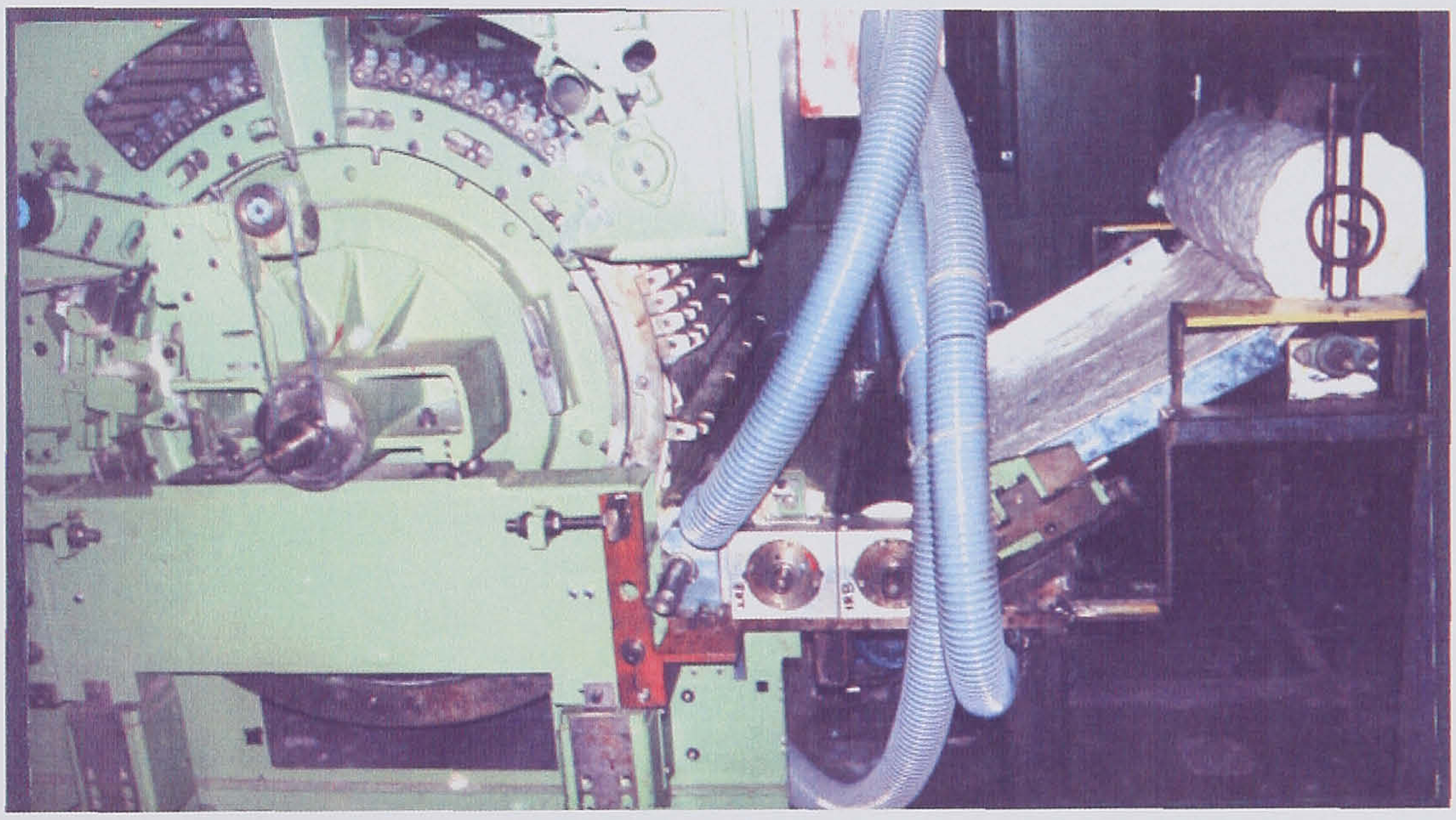


Figure 2.14 – Complete licker-in arrangement with waste suction, lap roller etc.

2.7.2 Installation of the triple licker-in at the University of Leeds

On completion of the quality trials at the spinning mills, the triple licker-in unit was transferred to the University of Leeds for further experiments. Here, due to practical difficulties associated with attaching the triple licker-in to the laboratory carding machine, it was decided to install the triple licker-in unit as a standalone system. Therefore, a suction unit was fabricated for suctioning the material from the third licker-in roller. The arrangement is shown in Figure 2.15 and Figure 2.16.

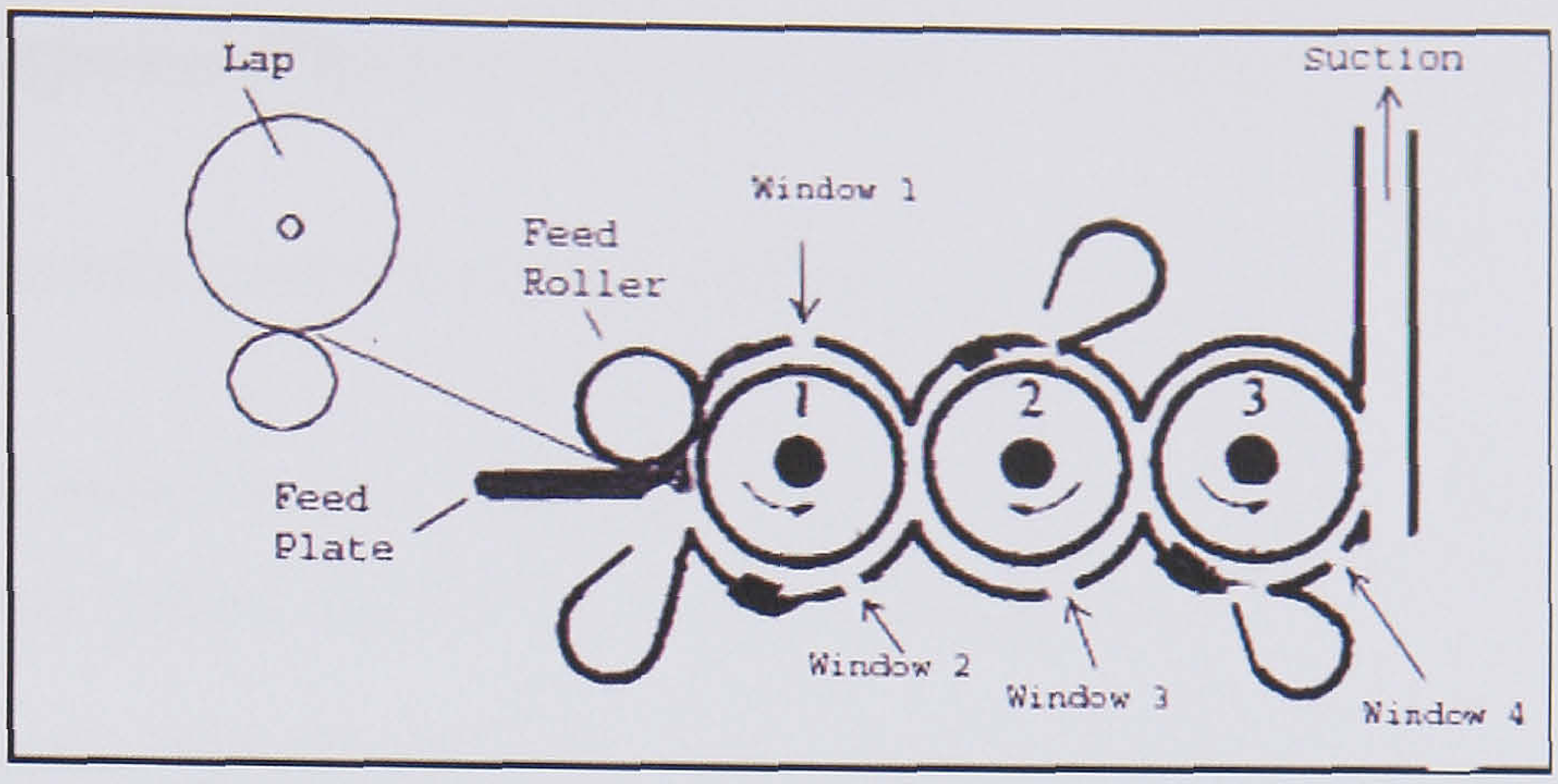


Figure 2.15: Triple licker-in arrangement with suction unit

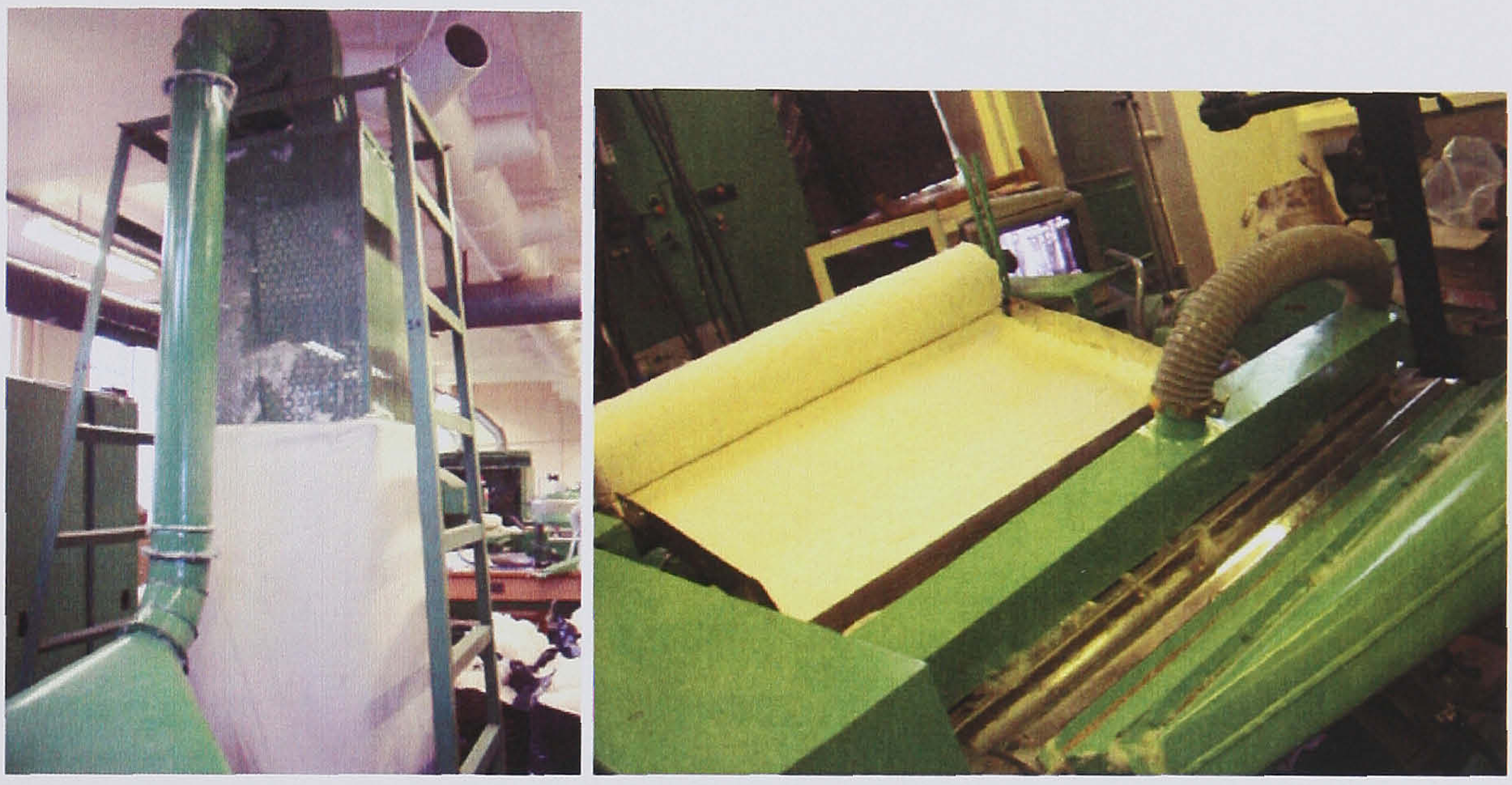


Figure 2.16 –Arrangement of suction used for the standalone triple licker-in unit

As can be seen in Figure 2.16, the suction unit consists of a suction fan that generates enough vacuum to remove the material from the third licker-in roller (third roller from the feed side) of the triple licker-in unit. The air is separated from the material at the perforated drum section under the suction fan and the fibres delivered were collected in the collection bag.

2.8 High-speed Photography of the Licker-in Surfaces

Three key elements involved in high-speed photography are:

1. a high-speed camera that can take pictures at a rapid rate so that the captured frames can reveal the object without blurring.
2. a powerful, high-speed flash of an extremely short duration
3. a synchronising system that can match the speed of the camera with the high-speed flash.

2.8.1 High-speed Camera

For this experimental work, a high-speed digital video camera was used. The system used was a Kodak HS Model 4540 capable of recording at 4500 frames per second (fps). The resolution of the sensor in this camera was 256 x 256 pixels. The system can record up to 4,500 fps with a full size picture (256 x 256 pixels) and with an increasingly smaller picture image up to 40,500 fps. This camera has been used successfully for high-speed photography of the carding surfaces at the University of Leeds in the past [40]. The speed and resolution used in the current work was set at 9000 fps and 256 x 128 pixels respectively for the single licker-in experiments and 4500 fps and 256 x 256 pixels respectively for the triple licker-in experiments. Initially, there were some problems in running the laser system to synchronise with the high-speed camera at 4500 fps and therefore the single licker-in experiments were run at 9000 fps. By the time the triple licker-in experiments were conducted, the laser was replaced with another of same type that synchronised with the high-speed camera better at 4500 fps.

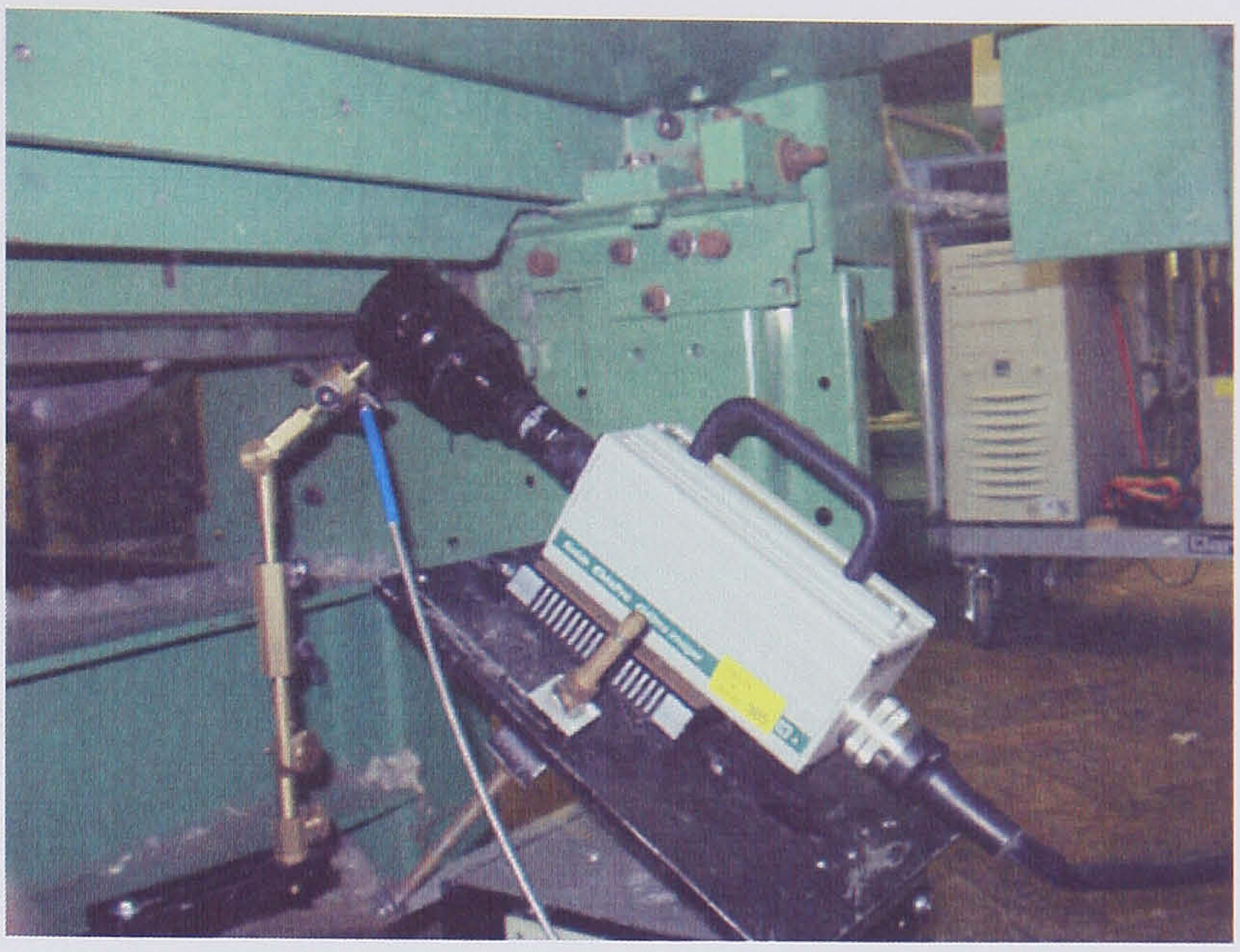


Figure 2.17 – High-speed camera, Lens and fibre optic for laser delivery

2.8.2 Lens

Two macro lenses were tried. One was a Canon TV zoom lens that was supplied along with the high-speed camera. The second was a TV 80mm lens, which was found to give the required image quality for subsequent analysis. The focal length of the lens used was 80 mm and to get the required image zoom, extension tubes were used. Table 2.5 gives useful information on the field of view, aperture value and extension tube size used.

Table 2.5: Information on camera set up

Licker-in	Lens			Field of View (mm)	Light Position
	Focal length (mm)	Extension tube length (mm)	Aperture value f		
Single Licker-in	80	45	4.5	18.3 x 9.2	Side
Triple Licker-in	80	70	2.5 - 4	13.1 x 13.1	Side

2.8.3 High-speed flash (Laser)

High-speed photography at 4500 or 9000 frames per second requires a high-intensity light source with short pulse duration. For this purpose, a pulsed copper vapour laser (Oxford Laser LS CU 15A) was used. Pulsed lasers not only improve the contrast and illumination of images taken, but because of the extremely short duration of flash, image blurring is eliminated no matter what the speed of the event. The Copper Vapour Laser system used for the experiments was air cooled and portable.

Some of the important specifications of the laser system used are given below.

Laser type:	Copper Vapour Laser, pulsed laser
Pulse rate:	Up to 30 KHz but generally 20 KHz
Pulse duration:	30 nanoseconds
Wavelength:	510.6 / 578.2 nm (Green /Yellow)
Average Output power (Watts)	Up to 15 watts at 10 KHz 8 watts at 20 KHz
Beam diameter (at laser end)	25 mm
Beam diameter (at fibre optic end)	1000 microns

2.8.3.1 Principle of working of the laser system [93]

The heart of the laser is the laser head assembly, which is a ceramic plasma tube that contains the copper charge, placed in the form of pellets along its length and which constrains the discharge. Laser operation occurs in copper vapour lasers through the collision of electrons with copper atoms that are present as a minority species in a high-speed longitudinal discharge. All this takes place in a buffer gas of high-purity neon. A temperature of 1400-1500 degree centigrade is required to achieve the vapour pressure of copper required for efficient laser action. In a copper laser, approximately 1% of the output power is converted to light output. The remaining 99% of the electrical output power is converted to heat. In the laser that was used for the experiments, up to an hour was necessary for the laser to reach full, stable power.

The light beam output from the laser is about 25mm in diameter and using suitable optics, it is converged to a diameter of 1mm (1000 microns), which is the diameter of the fibre optic delivery cable. The fibre optic cable is flexible and long enough to be taken to any position where the laser light is required.

2.8.4 Photography of Licker-in surfaces

The Crosrol Mark IV card has been used for high-speed photography for studies at the University of Leeds before [8]. Therefore, a suitable window was already available in the undercasing of the single licker-in for photography of the licker-in surfaces and is shown in Figure 2.18.

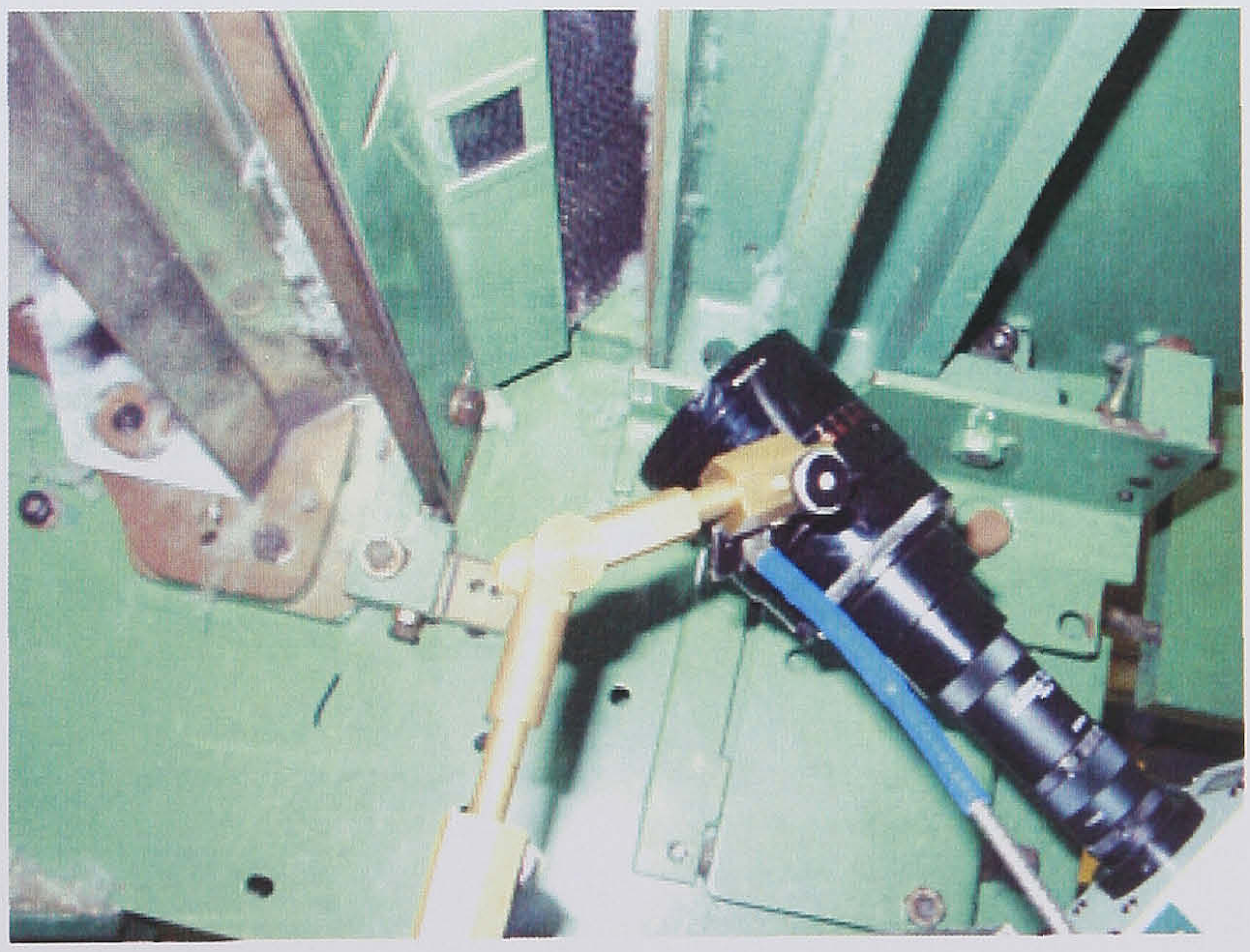


Figure 2.18 – Observation window for high-speed photography- Single Licker-in

Small windows of 1.5 cm by 5 cm were cut in the undercasings of each roller of the triple licker-in unit to photograph the licker-in surfaces (window positions shown in Figure 2.15, page 97). Microscopic slide glasses cut exactly to the window size were attached to the windows. Since the slides were nearly of the same thickness as the stainless steel sheet of the undercasing, there was a smooth internal finish enabling fibres to flow smoothly and preventing fibres from sticking over the window area. Figure 2.19 shows the high-speed photography being carried out on the third licker-in roller of the triple licker-in.

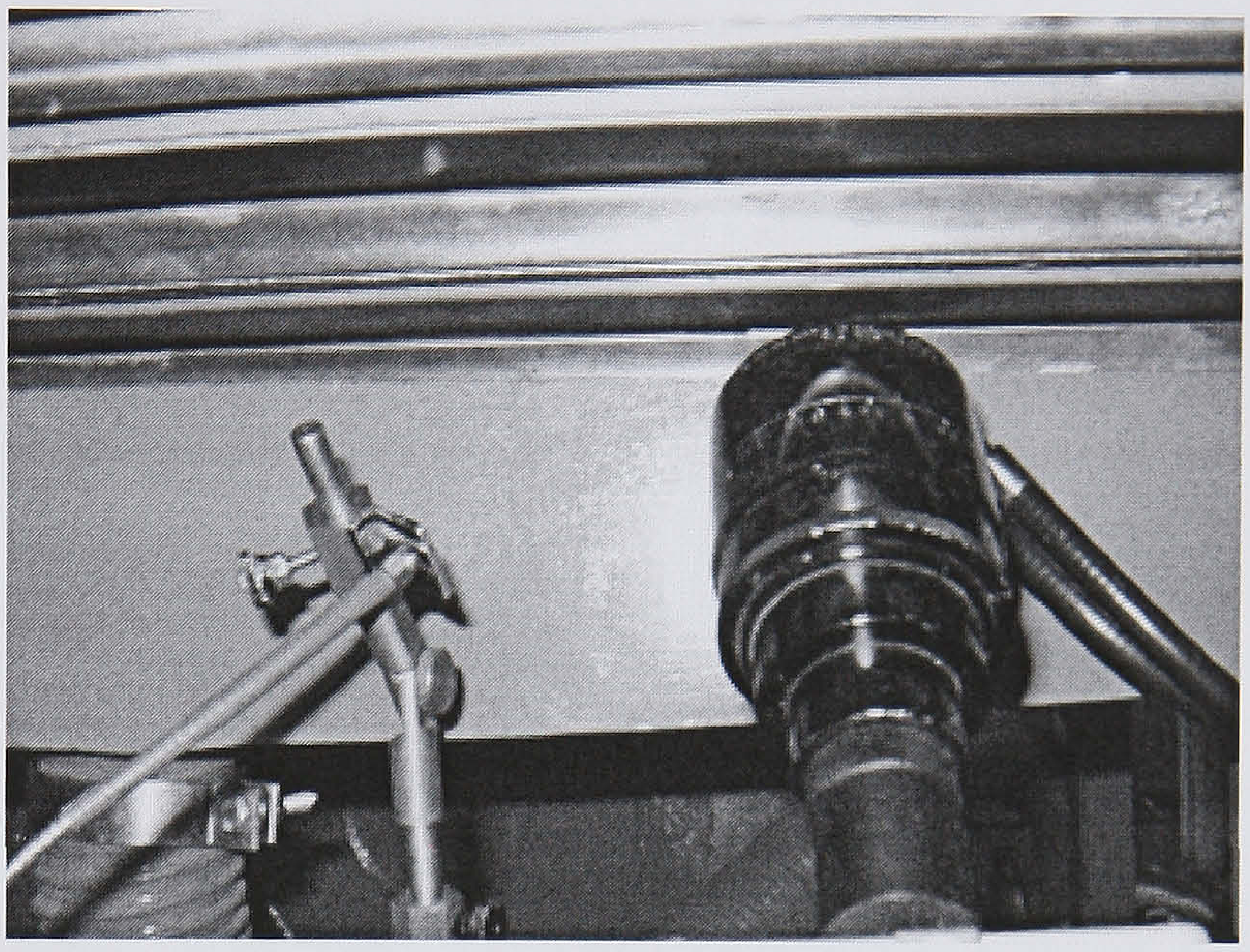


Figure 2.19 High-speed photography on the third licker-in roller

2.9 Image Analysis with Image Pro-Plus Software

2.9.1 Tracer Fibre Path Analysis in Yarns

The images of sections of yarn containing tracer fibres were first joined using Adobe Photoshop Version 7. Adobe Photoshop has a feature that allows creation of a large canvas on which the individual images can be placed and overlapped. Each image that is placed on the canvas is treated as a layer and once the overlap is complete, all the layers can be merged and thus one single long image can be created.

Paintshop Pro 7 was used to darken the tracer fibre paths although it is possible to do the same with Photoshop. However, the tool used for darkening the tracer path was found to be more user-friendly in the Paintshop software. Once the tracer path was darkened, it was possible to extract the black tracer fibre from the rest of the image by using the threshold function in Paintshop or Photoshop. The remaining details in the image disappear leaving only the yarn path visible (see Figure 2.20 and 2.21).

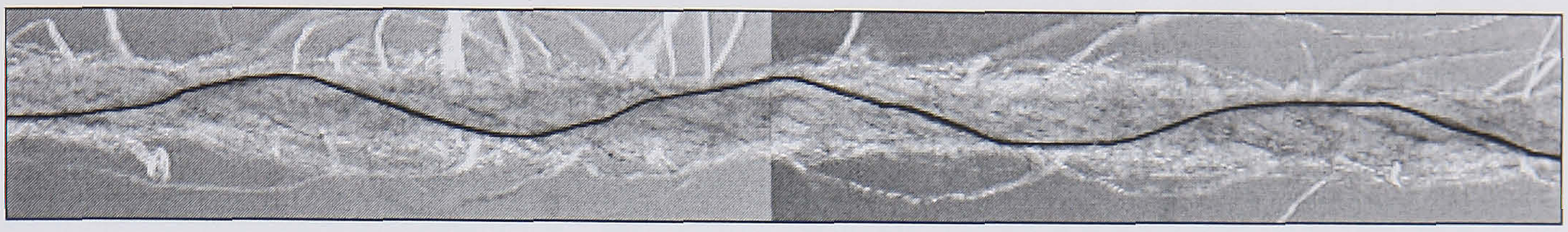


Figure 2.20: Tracer fibre in the yarn (traced)

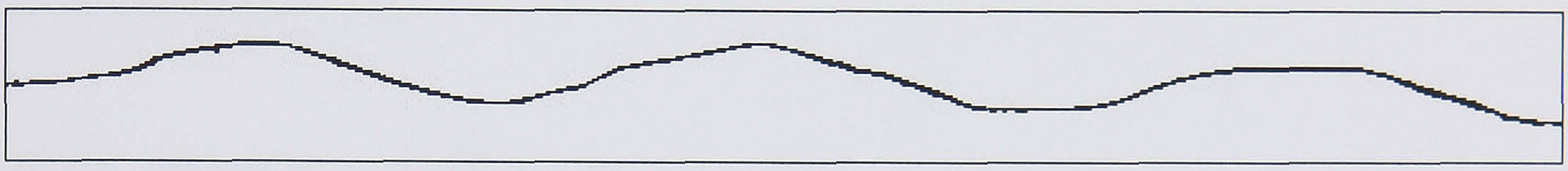


Figure 2.21: Tracer fibre extracted using software

The extracted tracer fibre path in the yarn can now be analysed using image analysis techniques. In this work, Image Pro-Plus Software Version 4 (Media Cybernetics) was used to measure the tracer fibre lengths and their extent within the yarn. Image Pro Plus is a powerful 'Windows' based image analysis software that is also user-friendly. It can perform image enhancement using colour and contrast filters, morphology, background subtraction and other spatial and geometric operations. It has features to trace and count objects, measure attributes such as area, angle, perimeter, diameter, etc. It is also possible to automate repetitive tasks and the software can be customised using the 'Macro' function. The software also allows the data to be exported to a Microsoft Excel worksheet for further analysis.

The most useful function that was used quite extensively for the tracer analysis was the 'trace' function. This function enabled the measurement of the tracer fibre length so accurately that it was possible to find even minor variations among the samples. Fibre extent was measured by measuring the beginning and end pixel positions of a tracer fibre.

2.9.2 Fibre Configuration on Licker-in surfaces

The images captured using the high-speed camera were processed in a similar manner to the yarn tracer fibre images. The white fibres on the licker-in were first traced using Paintshop and then the images (frames) were joined using Adobe Photoshop. The traced fibre length was then measured using the 'trace' feature of the Image Pro Plus Version 5. Fibre orientation was additionally measured by measuring the angle of the fibre to the Y-axis (machine direction) using the software. Fibre extent was measured by measuring the beginning and end pixel positions of the fibre.

2.10 Statistical Significance tests

Statistical tests of significance are a vital part of any investigation in order to comprehensively analyse the test results. Any sample that is tested for a particular characteristic or property is bound to show some variability in the individual test values. Therefore, when the means of two samples are compared, the variability must also be taken into account. Standard deviation and variance are used to denote the variability. Statistical tests of significance can compare either the means or variances in order to establish the significance of the results.

Main feature of this work was to observe trends when the licker-in or production parameters were varied with single and triple licker-in arrangements. Hence if there were noticeable and consistent trends in the results, it could likely be assumed that the results are significant. However, in addition, 't' tests were carried out to establish whether the mean values of the results were statistically significant at 95% confidence levels. The 't' values were calculated from the following formula [84].

$$t = \frac{(X_1 - X_2)\sqrt{n}}{\sqrt{(S_1^2 + S_2^2)}}$$

Where X_1 = Mean value of Sample 1

X_2 = Mean value of Sample 2

n = Number of tests carried out for Sample 1 and Sample 2

S_1 and S_2 = Standard deviations for Sample 1 and Sample 2 respectively

In this work, it was found that some of the important test results proved to be statistically significant in spite of smaller sample sizes and in some cases, clear trends were visible even though the results were not statistically different.

Chapter 3

Phase I Experimentation: Quality Studies with Single and Triple Licker-in Arrangements

3.1 Introduction

Phase I of this investigation estimates the extent to which the licker-in design governs the fibre, yarn and the resultant knitted fabric quality characteristics. In this investigation, two cotton varieties that widely differ in their characteristics were processed on a card, under controlled conditions, with the two commercial licker-in designs in use today viz. the single and triple licker-in designs, and the quality results are compared.

3.2 Methodology

The experiments were conducted at Super Spinning Mills, a leading textile yarn producer in India, which produces yarns for export in the range of Ne 20s to Ne 120s (29.5 tex to 4.9 tex).

The experiments were conducted on two Indian cotton varieties (NHH 44 and DCH 32). The fibre parameters measured with HVI and AFIS are given in Table I. While the NHH 44 cotton was spun to Ne 20s (29.5 tex), the DCH 32 was spun to Ne 80s (7.4 tex).

As seen from Table 3.1, the two cottons chosen differ widely in their characteristics so that they cover a fairly wide spectrum of cottons generally used for ring spinning. It is important to study the licker-in designs using cottons with widely differing characteristics so that the end results reflect the performance of the licker-in in practice.

Table 3.1: HVI and AFIS fibre test results

Fibre Parameter	NHH 44	DCH 32
HVI Results		
2.5 % span length	28.73 mm	34.94 mm
50 % span length	13.8 mm	17.13 mm
Uniformity ratio	48 %	49 %
Fibre strength in gms/ tex	21.73	26.73
Fibre elongation	5.9 %	7.9 %
Fibre micronaire value	4.1	3.0
Trash content %	3.64	3.62
AFIS Results		
Upper quartile length UQL (W)	29.29	34.18
Short fibre content (W) %	9.3	7.1
Fineness (millitex)	153	132
Maturity Ratio %	0.87	0.84
Immature fibre content %	7.5	7.4
Neps per gram	108	262

3.2.1 Blow-room

3.2.1.1 Mixing

The stack mixing technique was used to achieve a homogeneous mix. In this technique, cottons to be mixed are first weighed separately and then spread in thin layers one over the other. A number of layers make up one stack. The number of layers for each cotton depends on its proportion in the mix. The material is then withdrawn vertically from the mixing stack (by cutting down vertically) to be fed to the blending bale opener of the blow-Room.

One bale of cotton weighing 170 kg of each variety was hand opened and stack mixed. The opened material was spread uniformly as a thin layer on a clean surface and black dyed fibres measuring 0.05% by weight was dispersed uniformly over the spread for evaluation of fibre configuration in yarns, using the tracer fibre technique.

For these experiments, the vertically withdrawn material was additionally mixed again using the same stack mixing technique. This procedure was repeated 3 times to ensure that the materials were thoroughly mixed and to ensure that the black fibre was distributed uniformly throughout the mix. After mixing three times, the material was withdrawn vertically from the stack and fed on to the conveyor of the blending bale opener in the blow-room.

The processing sequences within the blow-room were carefully chosen based on the industrial practices used for the type of cotton studied. Laps were produced from the two cotton types to appropriate linear densities. A shorter sequence was selected for the DCH 32 cotton taking into account its longer staple length and fineness, to avoid fibre damage and increases in nep level.

The process sequence used for lap formation was as follows:

NHH 44:
Blending Bale Opener→ Axi-Flow Cleaner→ Porcupine Opener→ Saw tooth beater→ Krischner Beater→ Scutcher or Lap Former.

DCH 32:
Blending Bale Opener→ Step Cleaner→ Krischner Beater→ Scutcher or Lap Former.

Beater speeds are given in Table 3.2.

Table 3.2: Process Parameters in Blow-room

S.No	Beater	NHH 44	DCH 32
1	Mixing Bale Opener	550 rpm	550 rpm
2	Step Cleaner	Not used	400 rpm
3	Axi-Flow Cleaner	480 rpm	Not used
4	Saw Tooth Beater	450 rpm	Not used
5	Krischner Beater	820 rpm	820 rpm

3.2.2 Carding

The experiments carried out in the Indian spinning mill were conducted on a Crosrol Mark V High Production Card. This machine was chosen because there was a similar machine at the University of Leeds, where further experiments were to be carried out. The card chosen for the experiments was a well-maintained card with the age of the clothing of cylinder, doffer and flats being about a year old. All experiments were carried out on the same card in a production environment using single and triple licker-in arrangements, so that the carding conditions remained the same. The feed area of the card was modified to suit the triple licker-in unit.

The single licker-in of the Crosrol Mark V was 254 mm in diameter and was clothed with saw tooth metallic clothing used for cotton (see Table 3.4). The arrangement is shown in Figure 3.1.

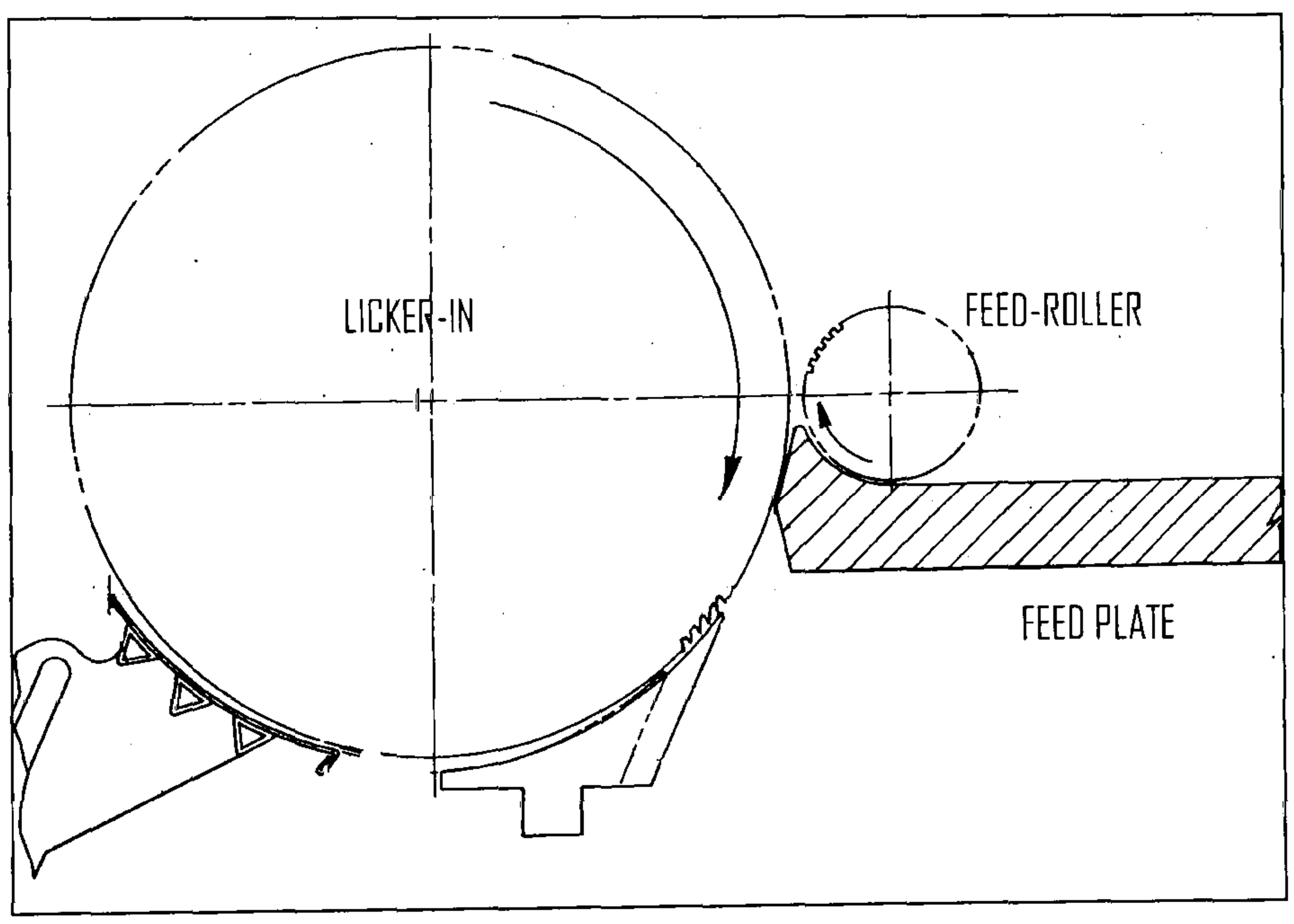


Figure 3.1: Single licker-in arrangement

Since the card was meant to use only a single licker-in arrangement, the feed area of the card was modified to suit the triple licker-in unit. A triple licker-in arrangement very similar in design to the commercially available model (Truetzschler DK 803) was fabricated in India. Suitable fixtures were fabricated for the Mark V card after removing the single licker-in system. The construction and installation of the triple licker-in arrangement was discussed in detail in section

2.7, Chapter 2. Figure 2.12 shows the construction of the triple licker-in arrangement used for the experiments.

3.2.2.1 Process parameters employed in carding

The process parameters such as the speed of lickers-in, cylinder and doffer, sliver linear density and the production rate were varied to suit the characteristics of the two cottons. The process parameters were chosen in consultation with the mill, as it had a wide experience in the processing of a wide range of cotton types. Table 3.3 shows some important process settings and speeds that were used for all experiments with the two licker-in arrangements.

Table 3.3: Process parameters in Carding

Parameter	**Cotton**	
	NHH 44	**DCH 32**
Feed plate to Licker-in setting	0.55 mm	0.55 mm
Licker-in to cylinder	0.175 mm	0.175 mm
Cylinder to Flats setting	0.2 mm	0.2 mm
Cylinder to Doffer setting	0.1 mm	0.1 mm
Cylinder speed	665 rpm 35.38 m/s	480 rpm 25.53 m/s
Flats speed	500 mm/min	360 mm/min

Roller dimensions and details of card clothing employed for the Crosrol card are given in Table 3.4.

Table 3.4: Roller dimensions and clothing details

	Licker-in		Cylinder	Flats	Doffer
	Single	Triple			
Diameter	254 mm	172 mm each	1016 mm		508 mm
Clothing used (Points per Square inch)	40	Roll 1 – 32 * Roll 2 – 161* Roll 3 – 206*	860	510	403

**Roll 1 –First Licker-in from feed end. Roll 2- Middle Licker-in. Roll 3 – Licker-in adjacent to cylinder.*

Settings in the licker-in zone of the triple licker-in arrangement are given in Table 3.5.

Table 3.5: Settings used in triple licker-in arrangement

Parameter	**Cotton**	
	NHH 44	**DCH 32**
Feed plate to Licker-in setting	0.55 mm	0.55 mm
Between Licker-ins	0.175 mm	0.175 mm
Lickers-in to carding segments	0.55 mm	0.55 mm
Licker-in to mote knife: Roll 1	1.2 mm	1.2 mm
Roll 2	2 mm	2 mm
Roll 3	2 mm	2 mm

The licker-in speeds and production rates used in the experiments are given in Table 3.6.

Table 3.6: Licker-in speeds and production rates for Single and Triple licker-in arrangements

PARAMETER	NHH 44 Cotton		DCH 32 Cotton	
Single licker-in				
	RPM	m/s	RPM	m/s
Single licker-in Speeds (3 different speeds)	1440 1080 840	19.15 14.36 11.17	1080 840 590	14.10 11.17 7.84
Sliver delivery rate in m/min	100		50	
Production rate in kg/hr	30		10	
Triple licker-in				
Licker-in speeds:				
Roll 1	998	8.99	755	6.80
Roll 2	1568	14.12	1202	10.83
Roll 3	2067	18.62	1516	13.65
Sliver delivery rate in m/min	100, 150, 200		50, 75, 100	
Production rates in kg/hr	30, 45, 60		10, 15, 20	

In the single licker-in arrangement, the speed of the single licker-in was varied, while the production rate was maintained constant for the following reasons.

1. For a given cotton, the approximate mill production rate achievable to produce a good quality yarn with a single licker-in arrangement is known by experience. However, the triple licker-in arrangement is claimed to increase the productivity by 30 to 100% [2] [55] over the single licker-in due to its improved opening and cleaning. The production rate was therefore maintained constant for experiments with the single licker-in and varied for the triple licker-in arrangement in order to confirm whether an improved opening in the licker-in zone permitted an increase in the production rate or an improved quality could be achieved at the same production rate.

2. According to some previous research work [46, 47] it is claimed that the licker-in arrangement has a considerable influence on the fibre configuration in slivers and yarns. Therefore, it is possible that the

licker-in speed, which determines the degree of opening, could also have a similar influence on fibre configuration. Hence, the licker-in speed was varied for the single licker-in to investigate this influence.

For the triple licker-in arrangement, three production rates were chosen, while the lickers-in were maintained at a constant speed. Speeds were not varied as the triple licker-in system mainly uses the stationary opening segments over or under the lickers-in to achieve the requisite opening. It was considered that fractional changes in the speed of rollers were unlikely to have a significant influence on the degree of opening. The speeds of the lickers-in of the triple licker-in arrangement were selected based on the cotton type, the mills experience using the cotton and on the recommendations of Truetzschler for their DK 803 card, which has a similar triple licker-in arrangement.

The production rate for the triple licker-in was increased over the single licker-in to ascertain whether an improved opening would permit increases in production, as claimed by Truetzschler for their DK 803 card with a triple licker-in arrangement.

To summarise, the experiments were conducted on a single licker-in arrangement with three licker-in speeds at a constant production rate and on a triple licker-in system with three production rates at a constant licker-in speed that suits the type of cotton. For each type of cotton, six samples were processed through the card.

3.2.3 Further Processing

The card slivers were given two passages through the draw-frame. Cherry Hara and Rieter RSB 851 draw-frames were used for the breaker and finisher passages respectively, and both the draw-frames were equipped with auto-levellers. The settings and break drafts were chosen according to the mill and industrial norms.

A Lakshmi-Rieter Speed frame with a 4 over 4 spring loaded drafting system was used for the experiments. Pilot Lakshmi-Rieter ring spinning frames, having 144 spindles each, were used to spin the yarns. They have a 3 over 3 double apron drafting system, which is pneumatically loaded.

The yarns were spun with a low twist multiplier for knitting purposes. The speeds and settings for processing were chosen based on the mill and industrial norms and are given in Appendix 5.

3.2.4 Testing of samples

3.2.4.1 Tests on fibre samples

Fibre samples from the raw cotton, lap and sliver stages were tested for neps, trash and fibre length. Neps were tested on AFIS (Advanced Fibre Information System) and residual trash contents were measured using the Shirley Analyser. Fibre length and its distribution were measured using HVI as well as on the AFIS (both supplied by Uster).

3.2.4.2 Tests on yarn samples

The yarn samples were tested for the following parameters:

1. Yarn linear density.
2. Single yarn strength and elongation using a Uster Tensorapid.
3. Yarn uniformity and imperfections (frequent faults) using a Uster Tester 4.
4. Infrequent yarn faults (Classimat) using a Classimat III tester.
5. Hairiness using Zweigle 566 tester.

3.2.4.3 Tests on knitted fabrics

Single jersey fabrics were knitted from the Ne 20s yarns using a knitting machine, which was 26 inches in diameter, and had a machine gauge of 24 needles per inch. Similarly, single jersey fabrics were knitted from the Ne 80s yarns using a knitting machine, which was 16 inches in diameter, and had 24 needles per inch. The fabrics knitted from the yarns were tested and graded for their pilling tendency according to test method IS: 10971-1984. They were also assessed for their visual appearance in terms of regularity and cleanliness. The details of methodology used were discussed in Chapter 2, Section 2.6.2.

3.3 Results and Discussion

The results of the investigations will be discussed with reference to the following considerations:

1. Carding performance
2. Ring spun yarn assessments
3. Fabric assessment

3.3.1 Carding performance

3.3.1.1 Card Waste

Detailed waste studies were conducted only at the lowest licker-in speed for the single licker-in experiments and only at the lowest production rate for the triple licker-in, due to time constraints. Only the licker-in waste was estimated at the highest licker-in speed (single licker-in) and highest production rate (triple licker-in). Card waste figures obtained are given in Table 3.7.

Table 3.7: Card Waste

	Single licker-in		**Triple licker-in**	
	NHH 44 (840 /1420 rpm)	**DCH 32 (590/ 1060 rpm)**	**NHH 44 (30/60 kg/hr)**	**DCH 32 (10/15 kg/hr)**
Licker-in Waste %	1.82 / 3.12	2.14 / 2.67	2.76 / 2.81	2.65 / 2.56
Total Card Waste %	5.64 / NA	5.2 / NA	6.18 / NA	5.66 / NA

3.3.1.2 Sliver Quality Results

The card sliver quality results are shown in figures 3.2 to 3.9. In these results, the triple licker-in at 30 kg/hr for NHH cotton and triple licker-in at 10 kg/hr has been used as the reference (indicated by the letter 'R') from which the quality changes with the single and triple licker-in parameters are compared. This was because at the production rates mentioned above, the single licker-in had three different speeds, while the triple licker-in had no other variable.

Note:

1) I and III refer to the single and triple licker-in respectively.

2) Percentages are given with respect to the reference case (R) i.e. Triple licker-in at 30 kg per hour for NHH cotton and Triple licker-in at 10 kg per hour for DCH 32 cotton

3) The triple licker-in speeds in rpm (rolls 1, 2, 3) were 998, 1568, 2067 for NHH 44 and 755, 1202, 1516 for DCH 32 respectively.

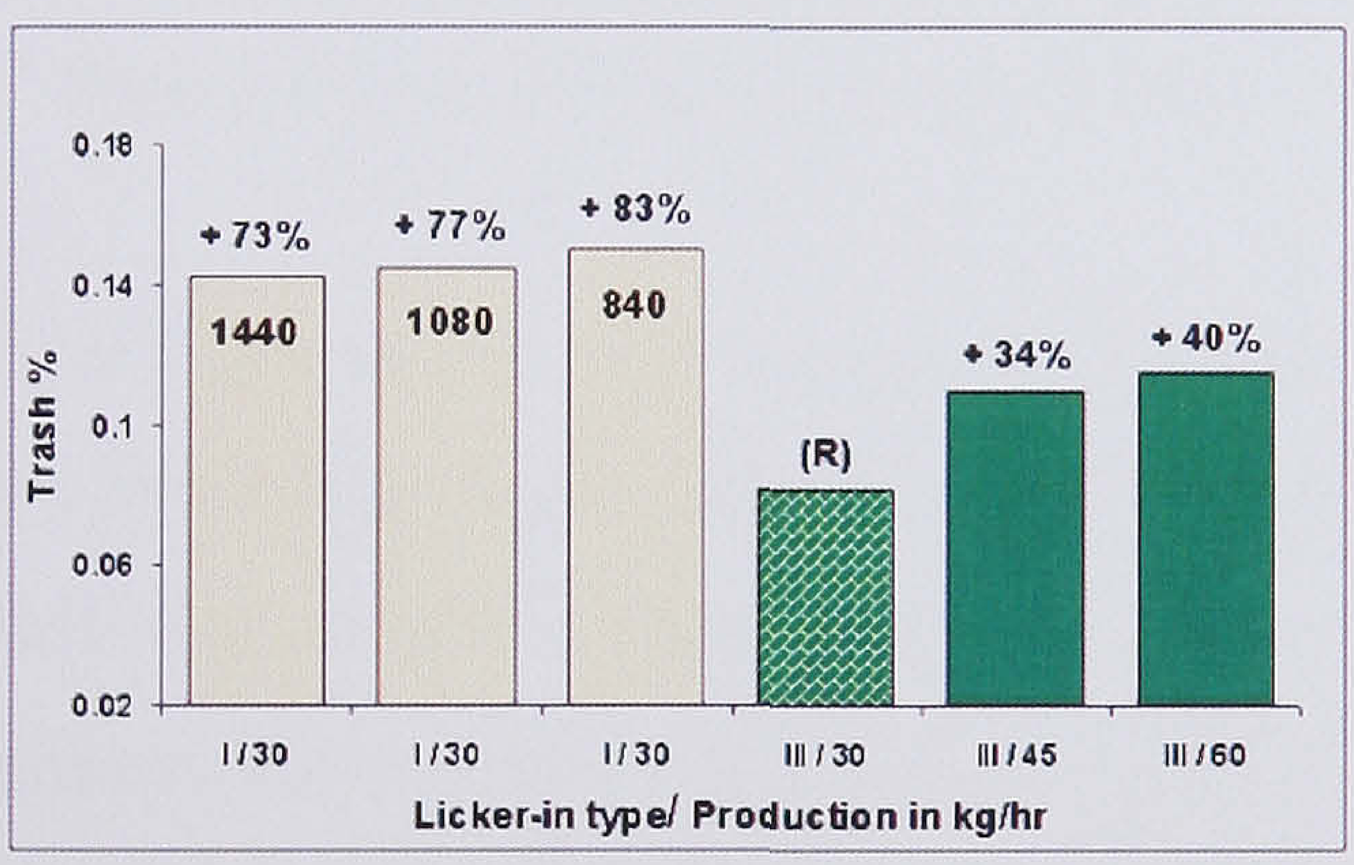


Figure 3.2: Sliver trash% for NHH 44

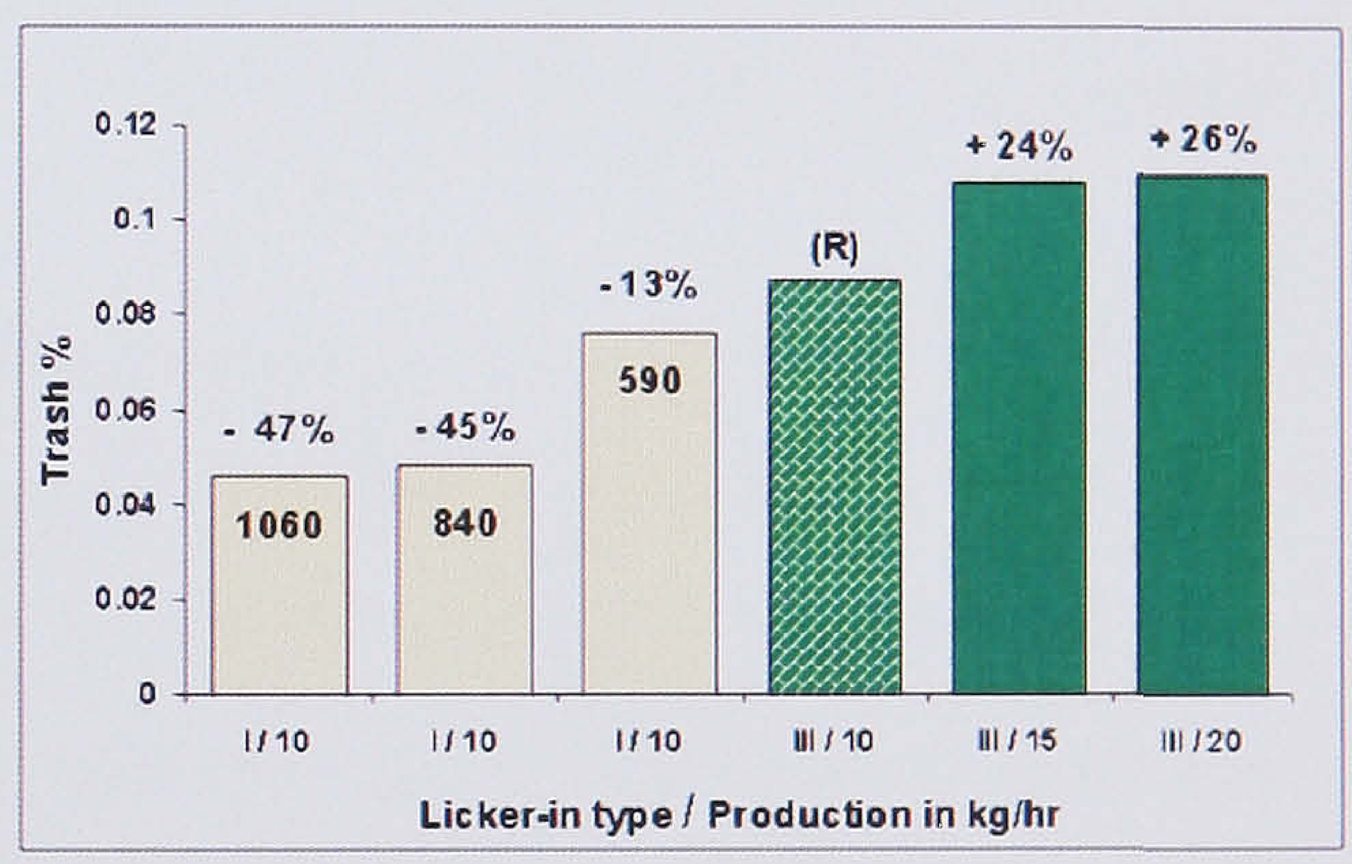


Figure 3.3: Sliver trash% for DCH 32

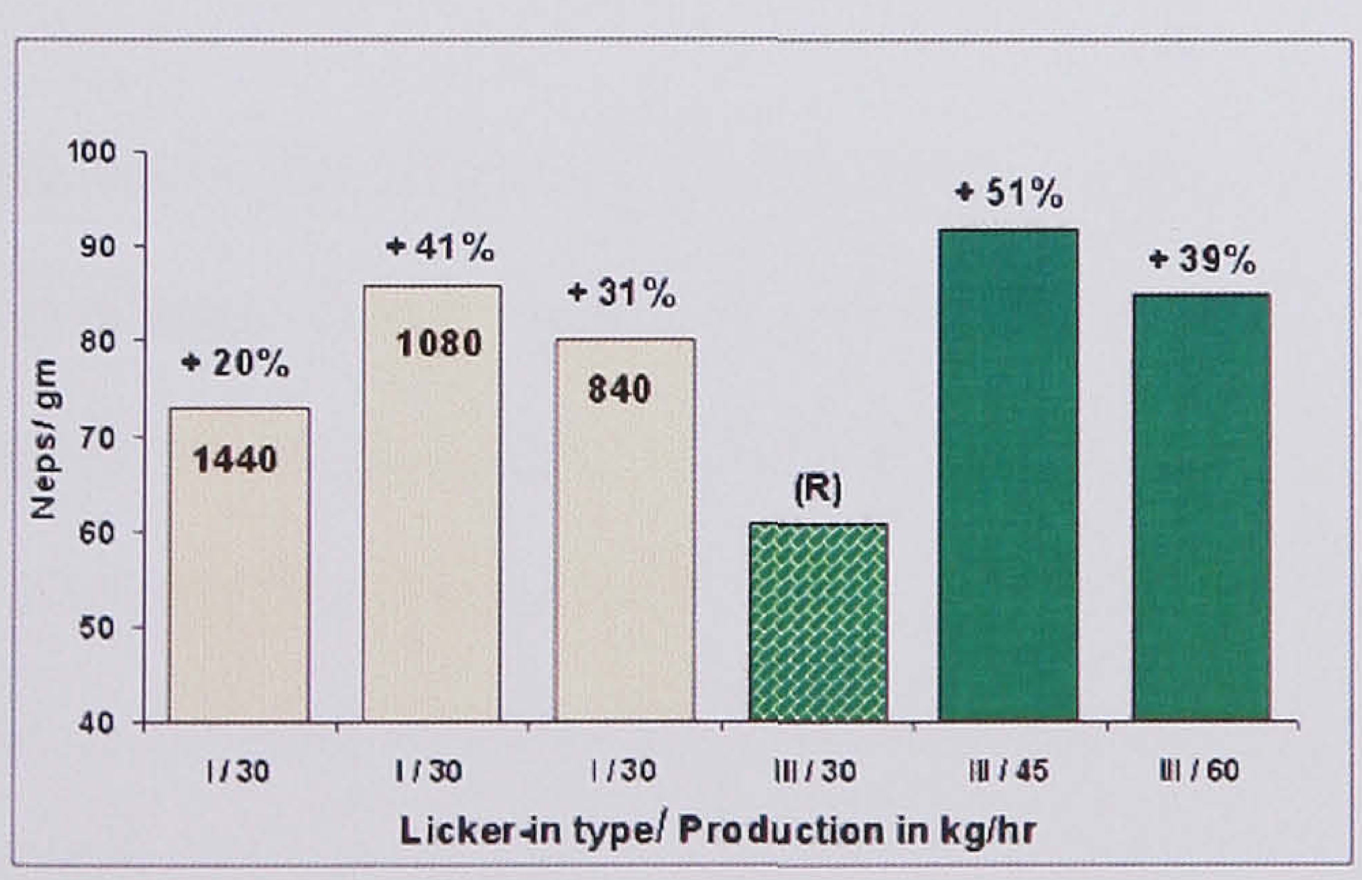


Figure 3.4: Sliver neps for NHH 44

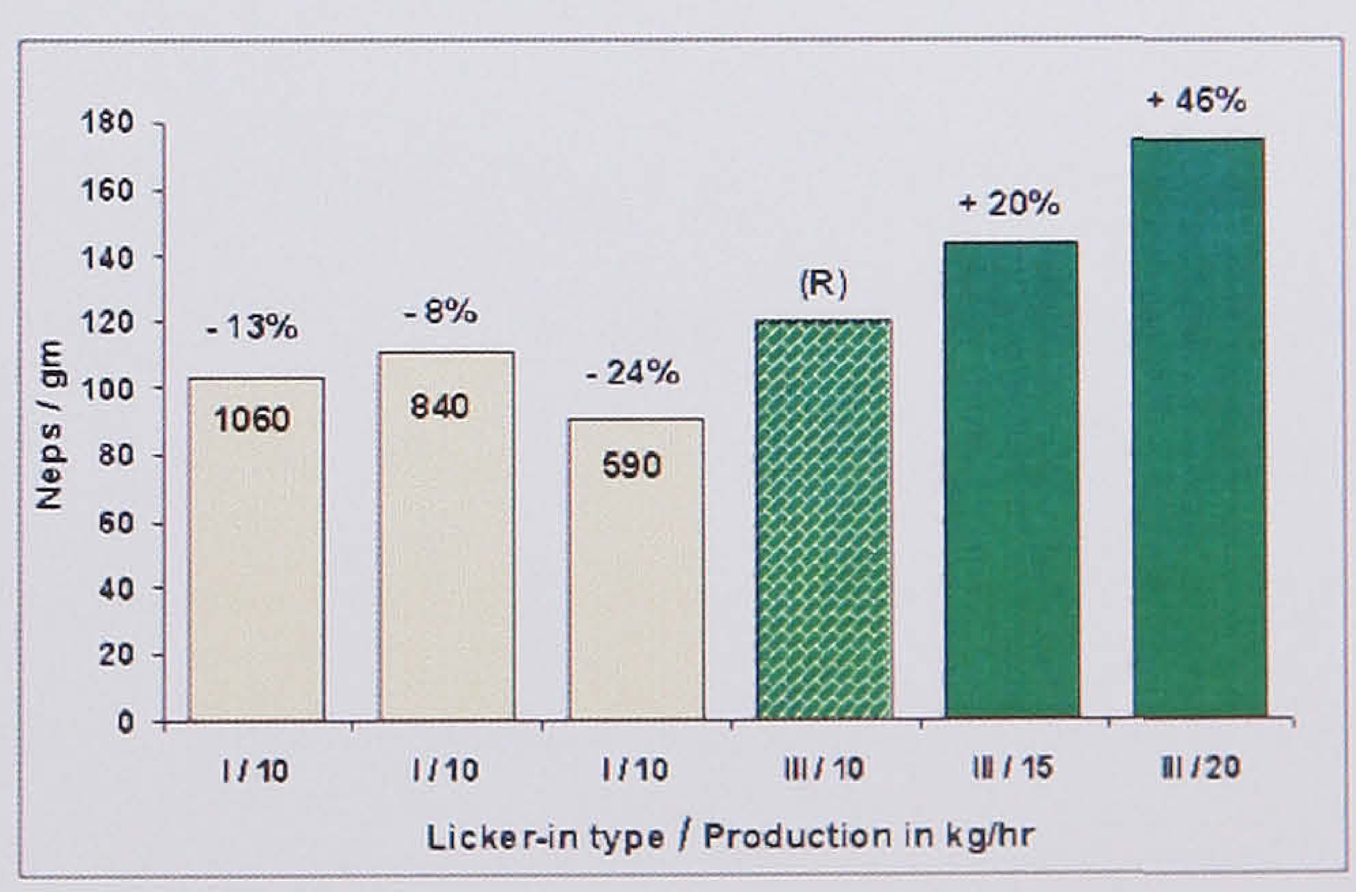


Figure 3.5: Sliver neps for DCH 32

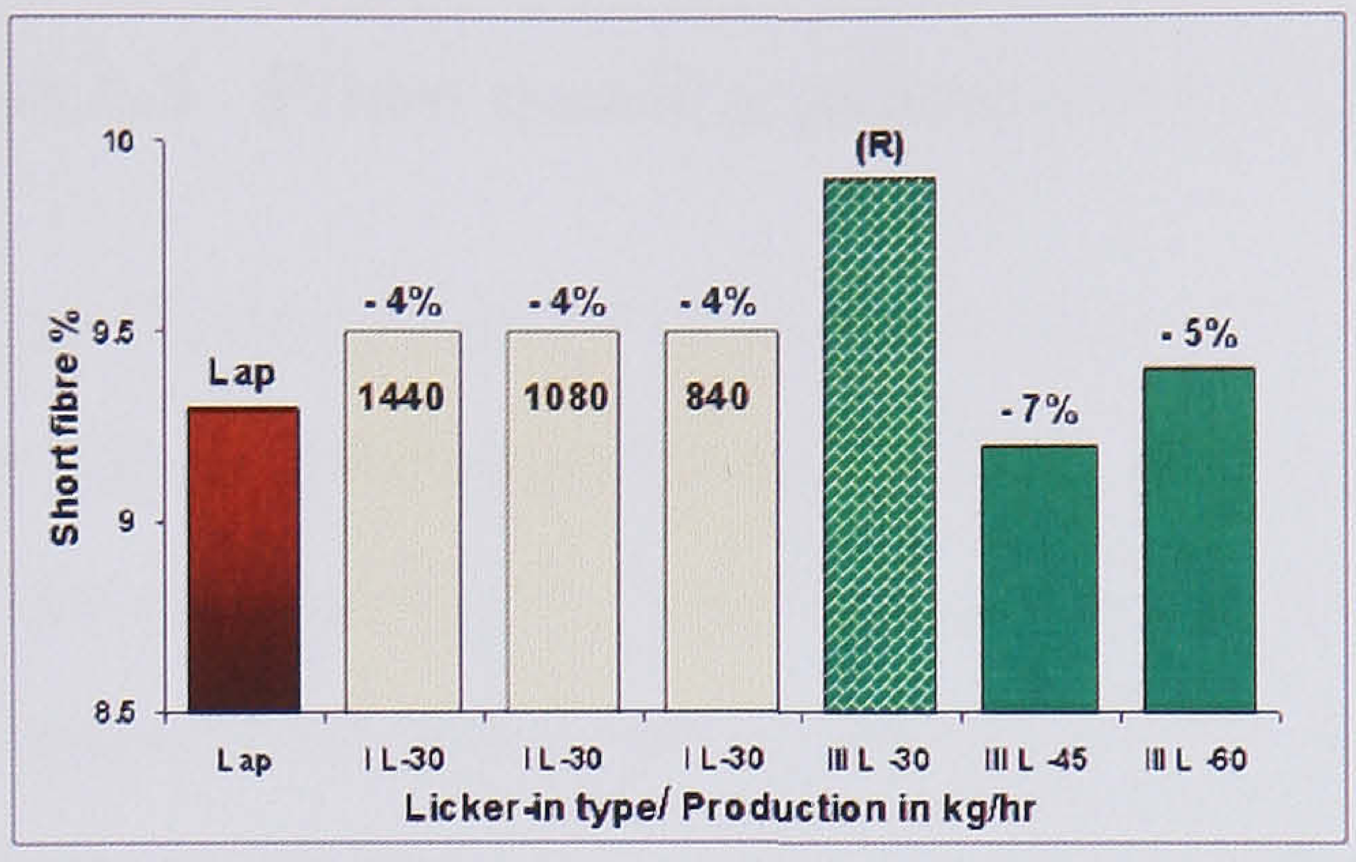


Figure 3.6: Sliver short fibre% for NHH 44

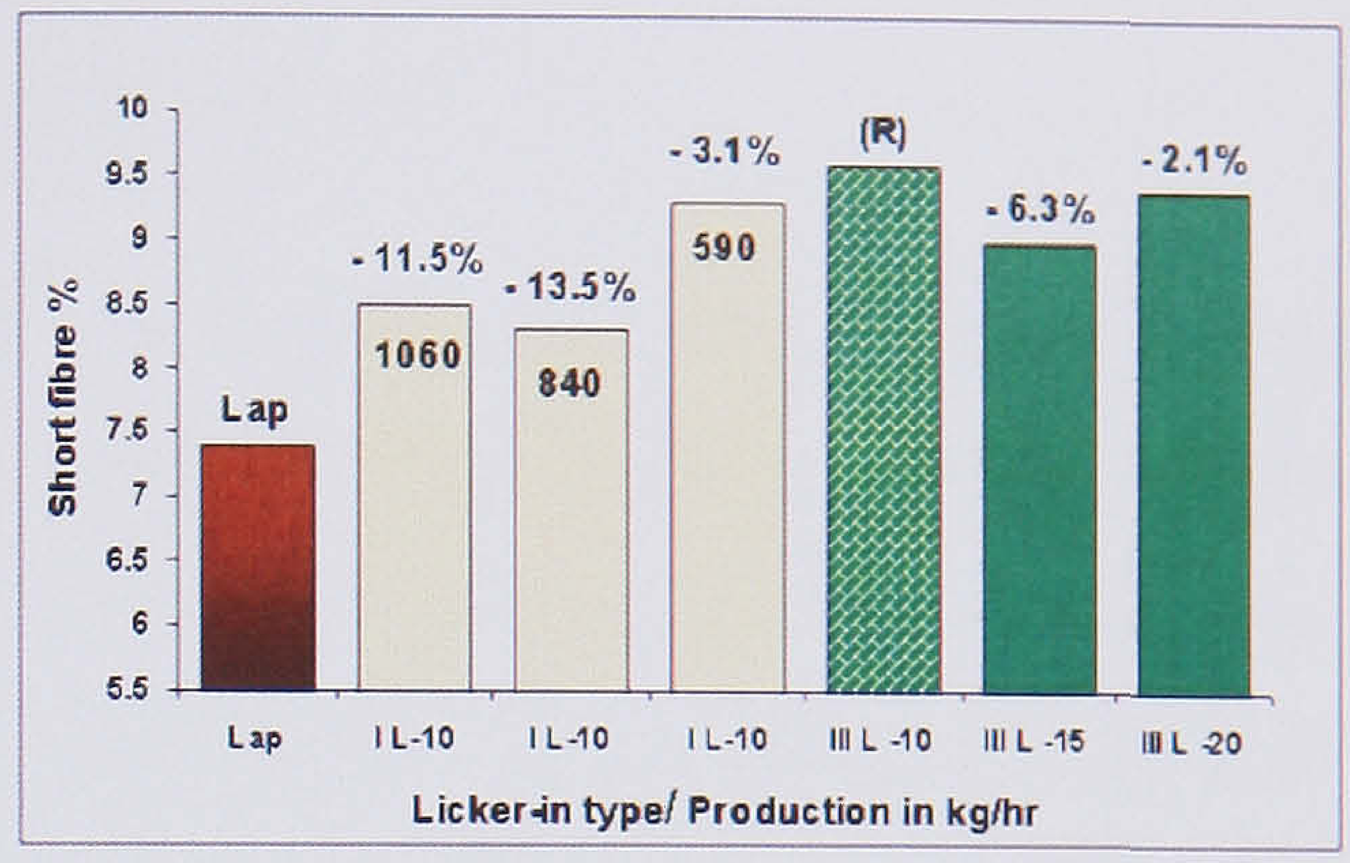


Figure 3.7: Sliver short fibre% for DCH 32

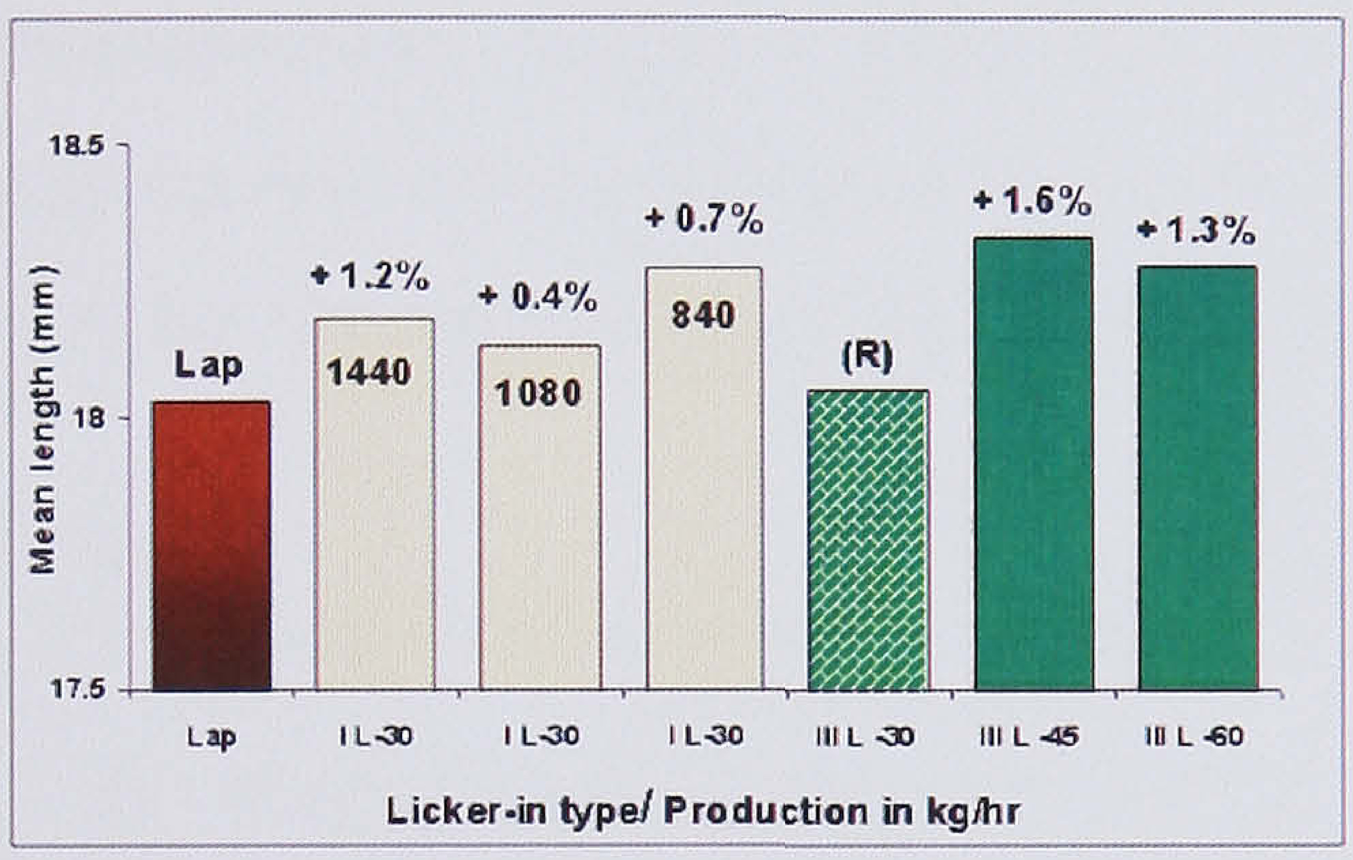


Figure 3.8: NHH 44 Sliver mean length

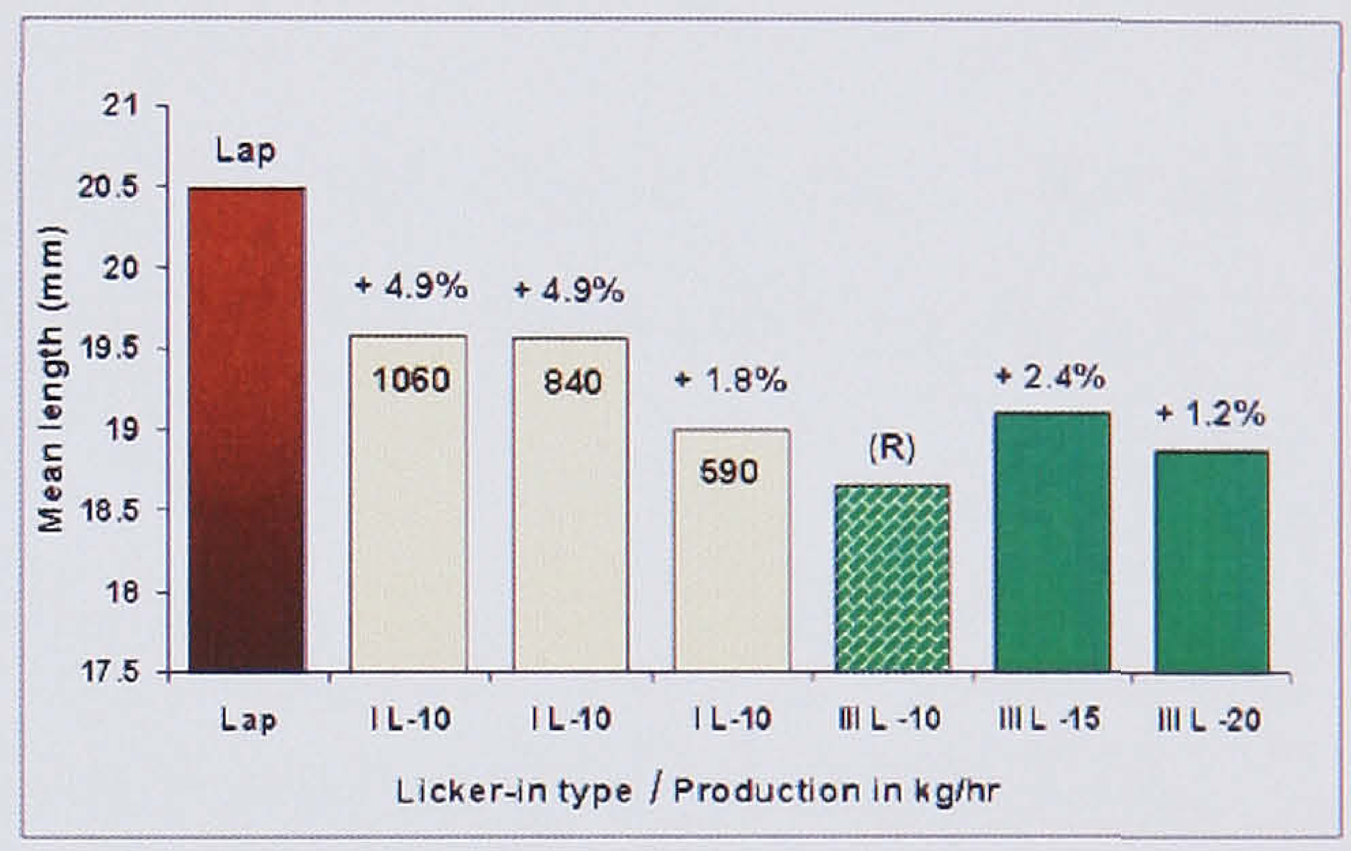


Figure 3.9: DCH 32 Sliver mean length

From Figures 3.2 and 3.4, it can be seen that when processing NHH 44 cotton, the card with the triple licker-in has a better cleaning efficiency and lower nep levels than the single licker-in at the same production rates and interestingly has comparable values even at the highest production rate. However, with DCH 32 cotton, the nep and trash levels of triple licker-in sliver are inferior to the single licker-in slivers at all production rates (Figures 3.3 and 3.5).

The results (figures 3.6 to 3.9) also reveal that neither the mean fibre length nor the short fibre content (fibres shorter than 12.7 mm in length) show any clear trend with change in licker-in speed for the single licker-in. For both the licker-in systems, the mean fibre length is generally greater in the sliver than in the lap of the medium staple NHH 44 cotton. For the longer DCH 32 cotton, the mean fibre length in the slivers is lower and the short fibre content slightly greater than in the lap material. This indicates of a possible reduction in fibre length of the longer group of fibres with both licker-in arrangements.

3.3.1.3 Fibre quality parameters on the licker-in

The triple licker-in unit used for the quality trials in the spinning mill was brought to the University of Leeds for further experiments using high-speed photography. The arrangement used for experiments in the University of Leeds is shown in Figure 2.16 (Chapter 2, page 97). In order to determine the extent of changes in fibre length and nep level at the licker-in stage, fibre samples were carefully collected from the licker-in surfaces of both the single and triple licker-in arrangements using a powerful suction (industrial vacuum cleaner). These experiments were conducted on a Crosrol Mark IV card and the triple licker-in unit used for the experiments. The fibre quality results are given in figures 3.10 to 3.17.

Note:

1) I and III refer to single and triple licker-in respectively.
2) Single licker-in speeds are indicated over the individual bars as 590, 840, etc.
3) The triple licker-in speeds in rpm (rolls 1, 2, 3) were 1024, 1632, 2068 for NHH 44 and 785, 1252, 1584 for DCH 32 respectively.

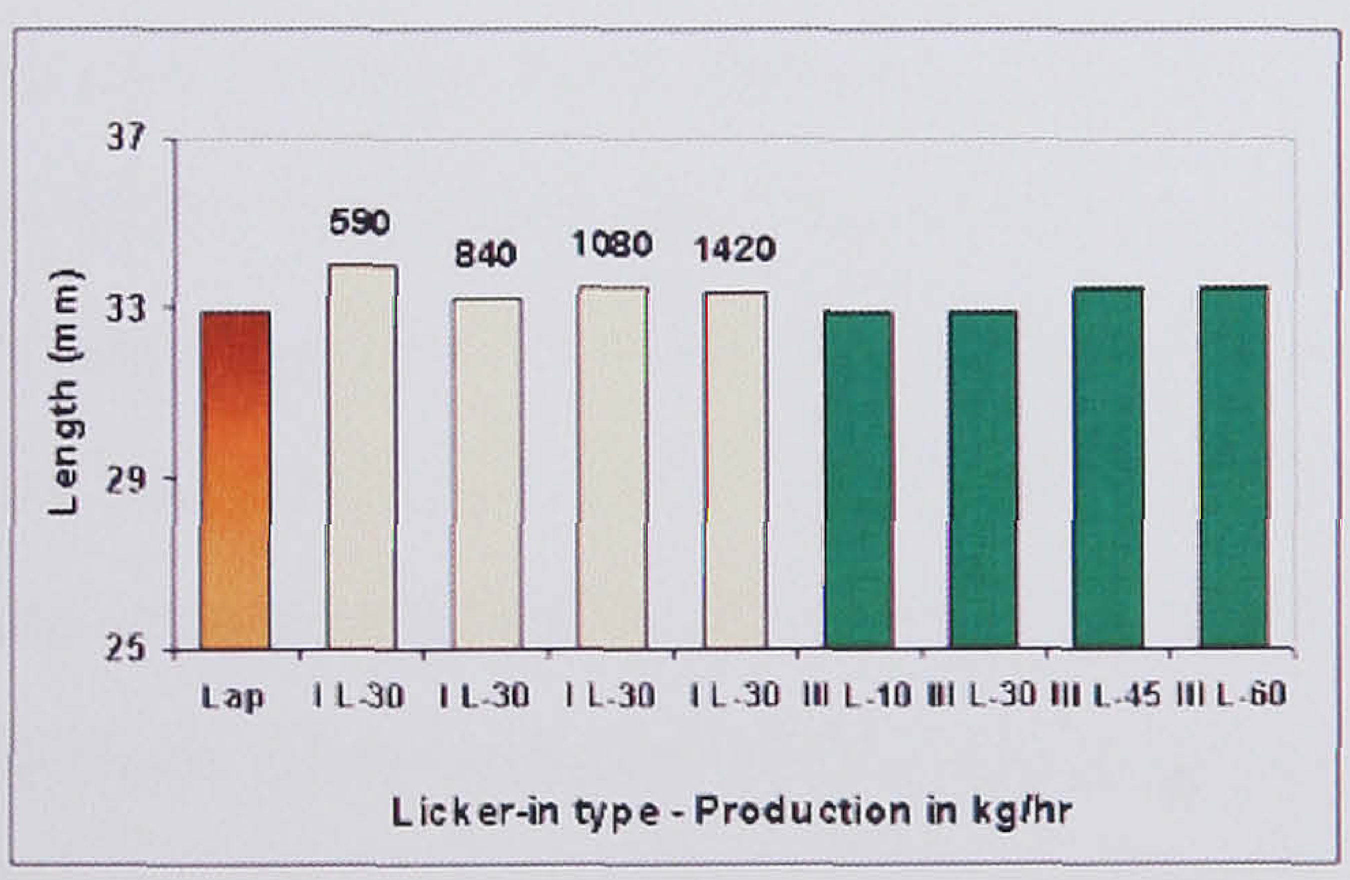


Figure 3.10: NHH 44 AFIS 5% length

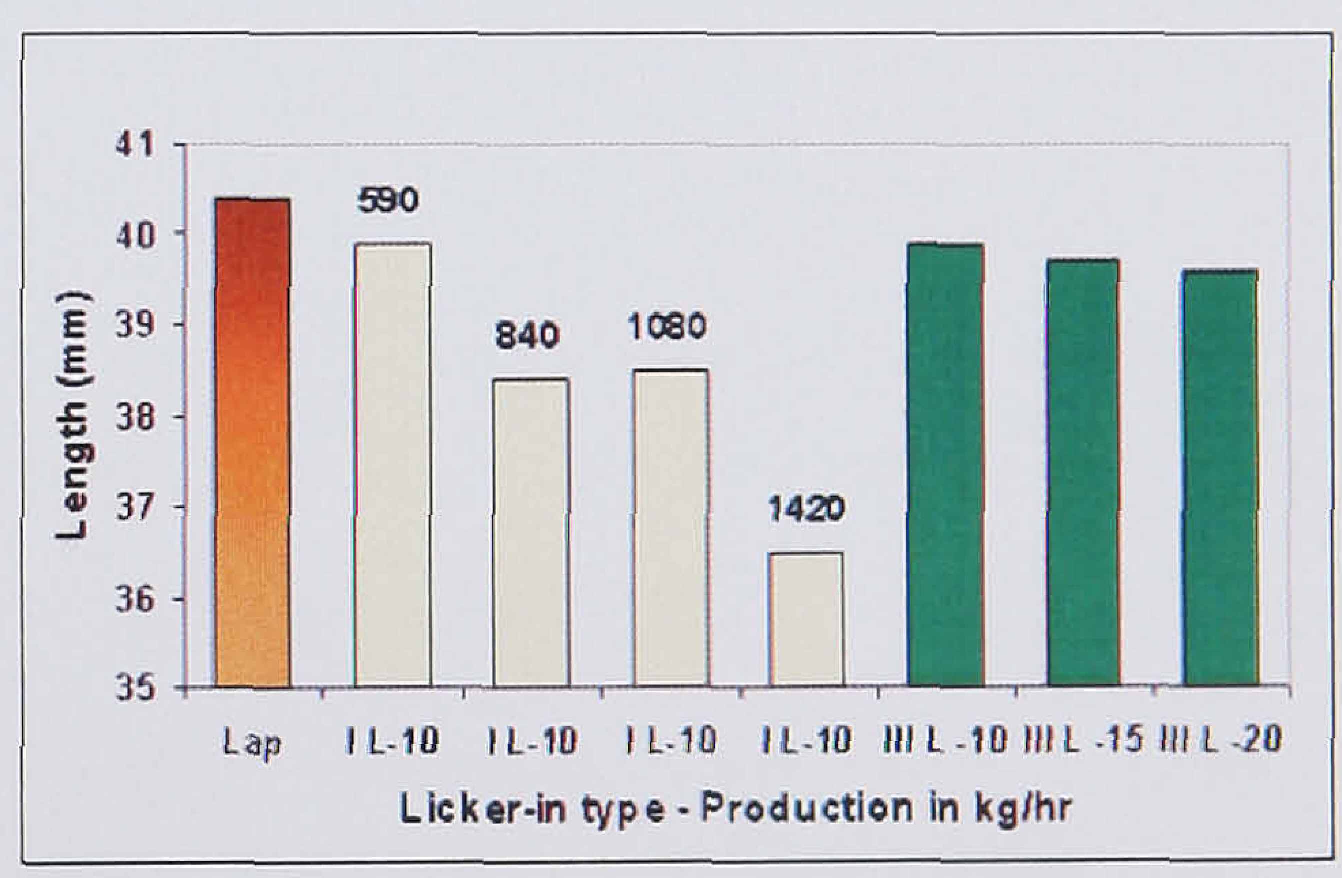


Figure 3.11: DCH 32 AFIS 5% length

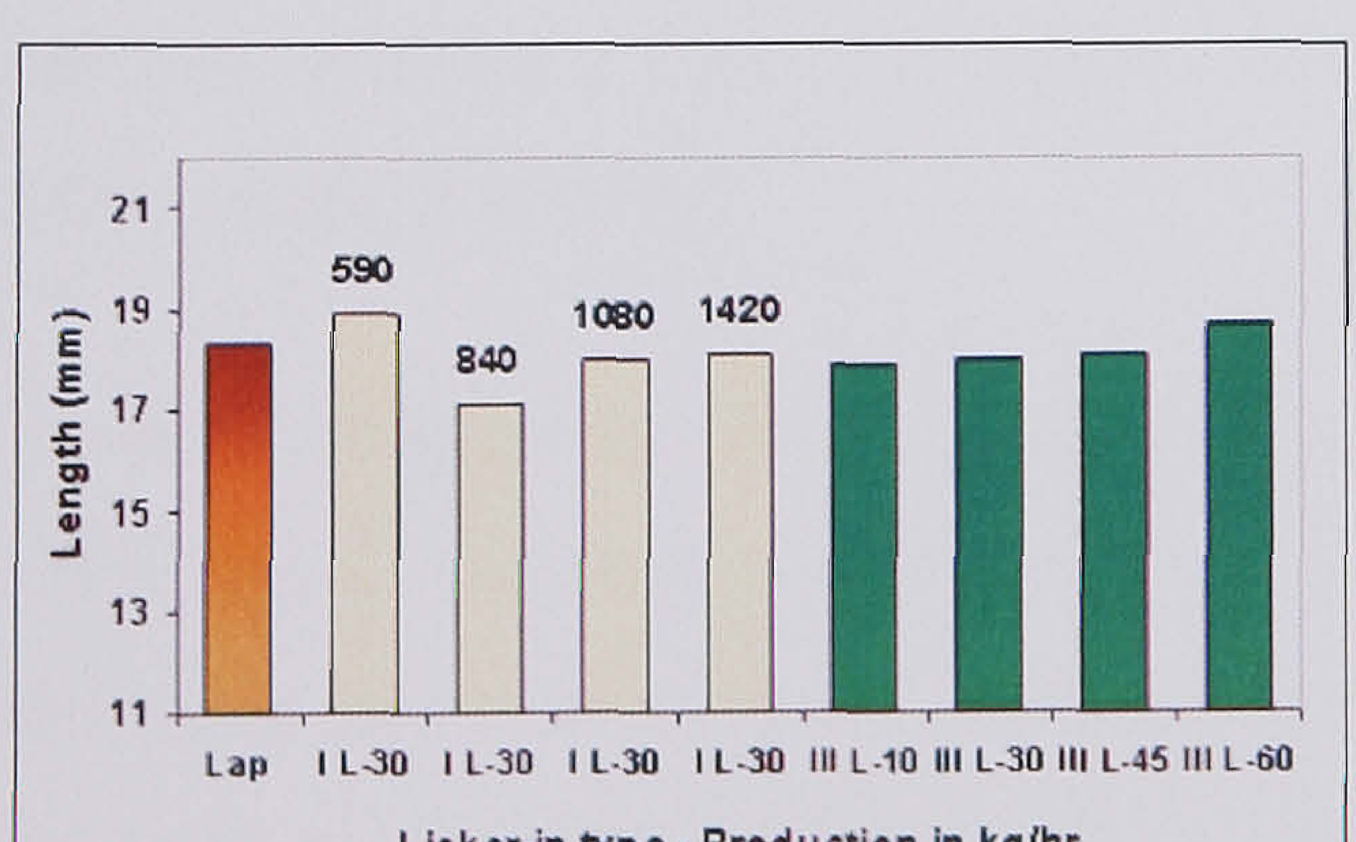


Figure 3.12: NHH 44 AFIS Mean Length

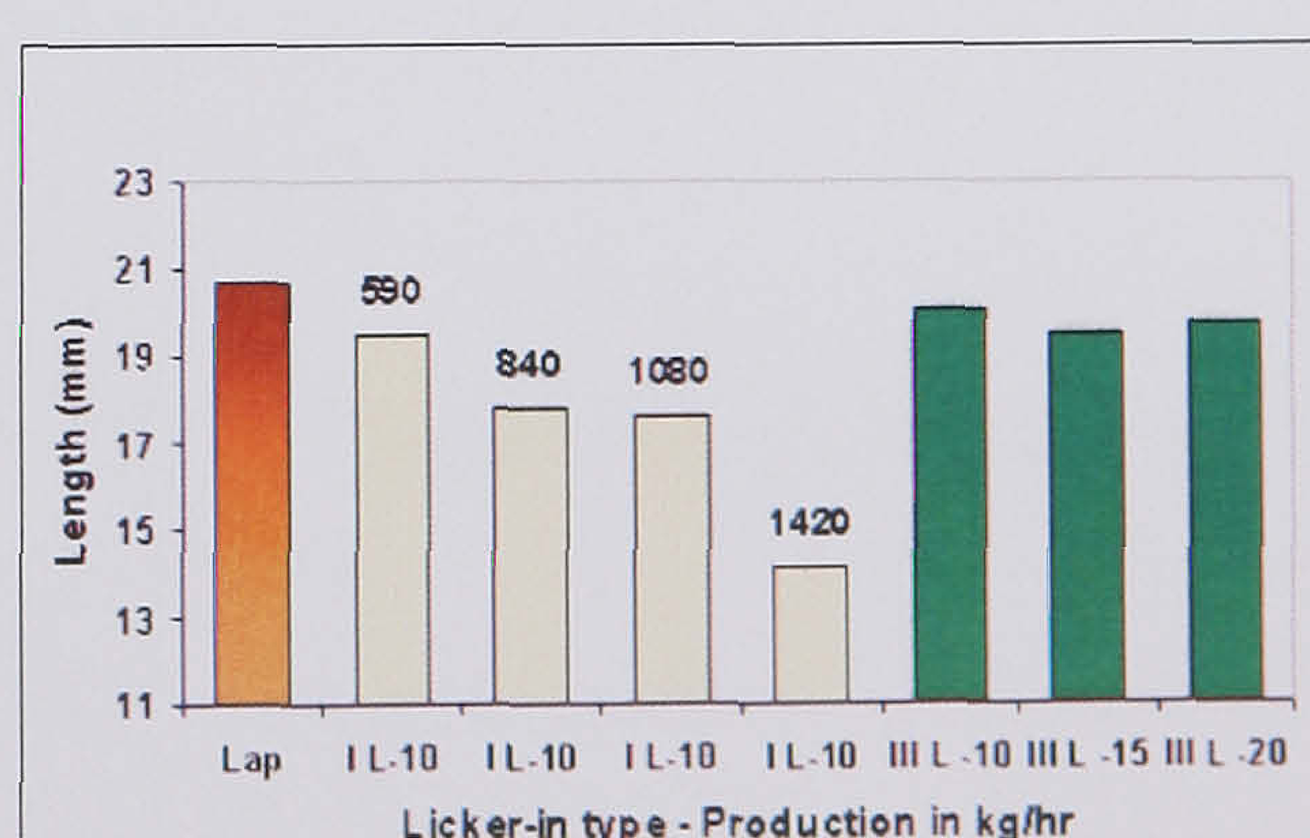


Figure 3.13: DCH 32 AFIS Mean Length

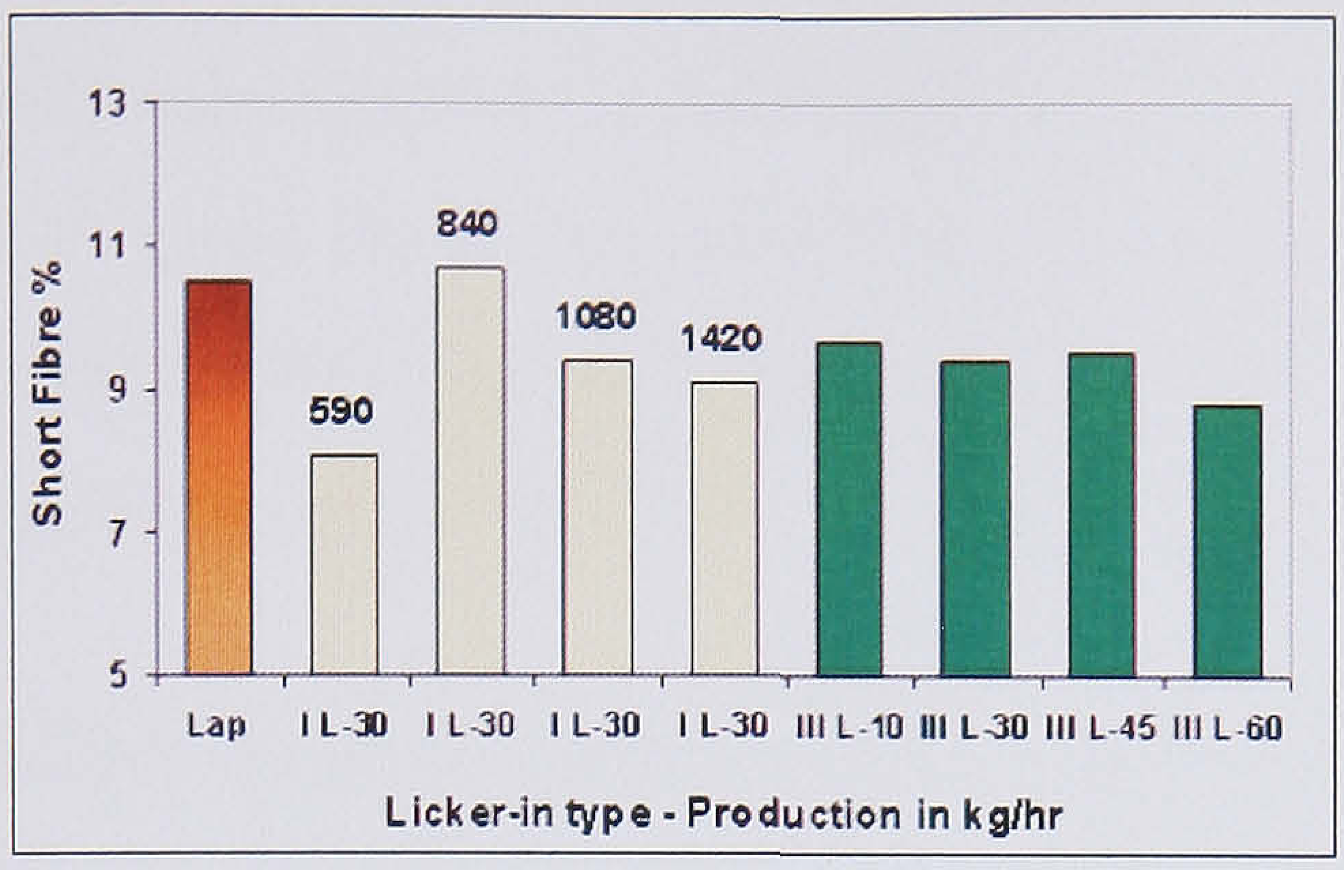


Fig. 3.14: NHH 44 AFIS Short Fibre Content

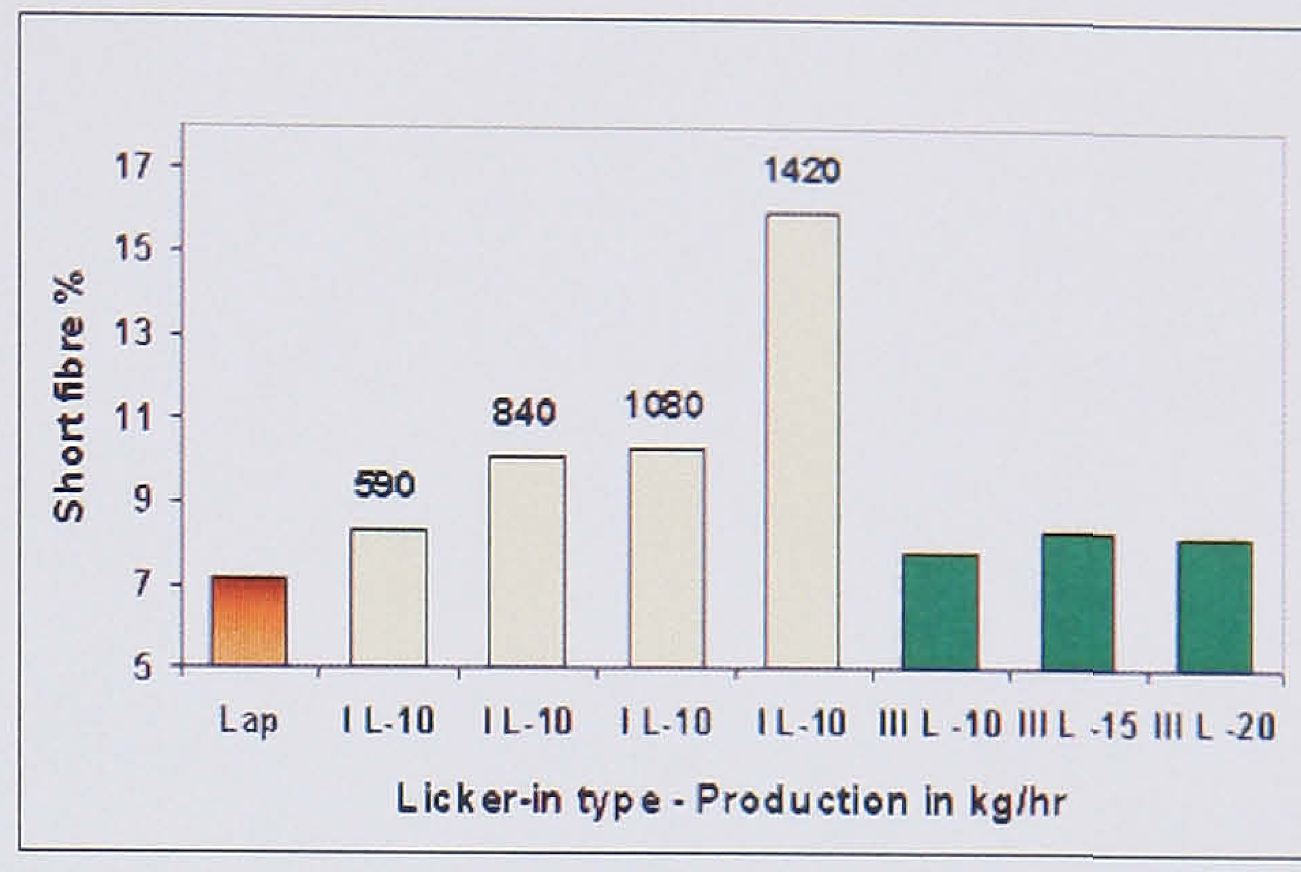


Fig. 3.15: DCH 32 AFIS Short Fibre Content

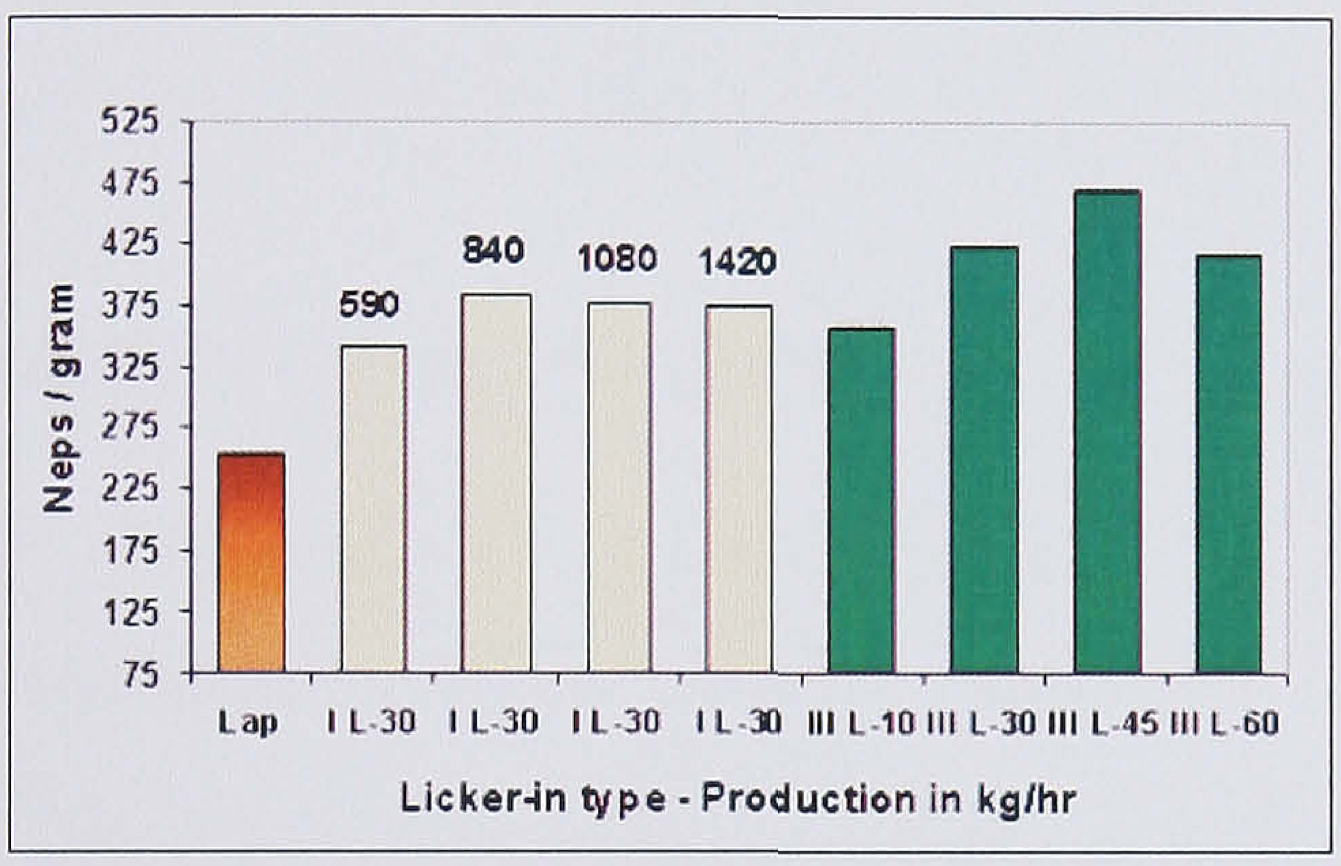


Figure 3.16: NHH 44 AFIS Nep Content

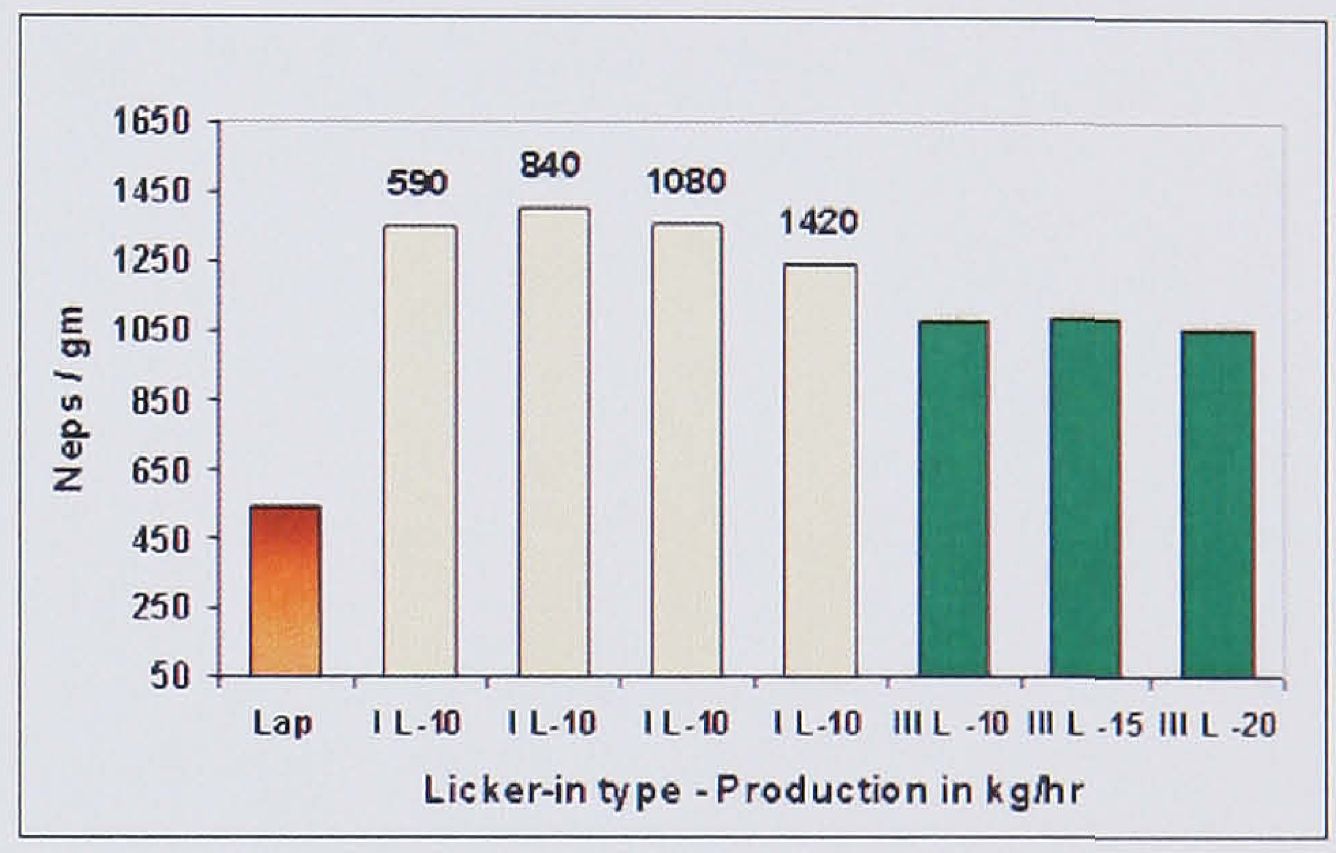


Figure 3.17: DCH 32 AFIS Nep Content

As can be seen from figures 3.10 to 3.15, there is clear evidence to show that there is fibre breakage in the licker-in zone with both licker-in arrangements while processing the long and fine DCH 32 cotton. Breakage of longer fibres is evident by the reduction in AFIS 5% length. The short fibre content increases dramatically in the case of the DCH 32 cotton, especially at the highest speed. There is an increase in short fibre content and a simultaneous reduction in mean length as the licker-in speed is increased from 590 rpm to 840 rpm in the case of medium staple cotton like NHH 44 (with average fineness). Triple licker-in shows less fibre damage in the case of slender DCH 32 cotton, where as with the NHH 44 cotton, it is similar to the single licker-in.

There is a significant increase in nep level with the longer DCH 32 cotton (125% to 160% appx.) processed on a single licker-in (Figure 3.17). Another significant finding is that the triple licker-in generated fewer neps than the single licker-in in the case of the fine DCH 32 fibres, whereas it generated more neps than single licker-in at same production rates with NHH 44 cotton and neps show an increase with an increase in production rate with the triple licker-in (Figure 3.16). However, it is clear from the sliver results that even though single licker-in generated more neps in the case of DCH 32, the card was able to remove most of them and the sliver quality was better than produced on the triple licker-in for this cotton.

3.3.2 Ring spun yarn Assessments

As mentioned in methodology section, the medium staple, medium fine NHH 44 cotton was used for spinning coarse ring yarns of 29.5 tex (Ne 20s) and the long and fine DCH 32 was used for spinning fine yarns of 7.4 tex (Ne 80s).

3.3.2.1 Coarse ring spun yarn results

At the production rate of 30 kg/ hour, the yarn quality in terms of Uster yarn irregularity, thick places, neps, Classimat 'A1' faults and Classimat total faults (Figures 3.18 to 3.23) is better with the triple licker-in than with the single licker-in. As the production rate is increased, the yarn faults and irregularity also increase, though not proportionately. The yarn thin places (-30%) have been compared instead of thin places (-50%), as they (-50%) remained at less than unity for all experiments. In the following figures, the triple licker-in at 30 kg/hr has been used as the reference (indicated by the letter 'R') from which the quality changes with the single and triple licker-in parameters are compared and indicated.

Note:

1) I and III refer to the single and triple licker-in respectively.
2) The triple licker-in speeds in rpm (rolls 1, 2, 3) were 998, 1568, 2067 respectively.

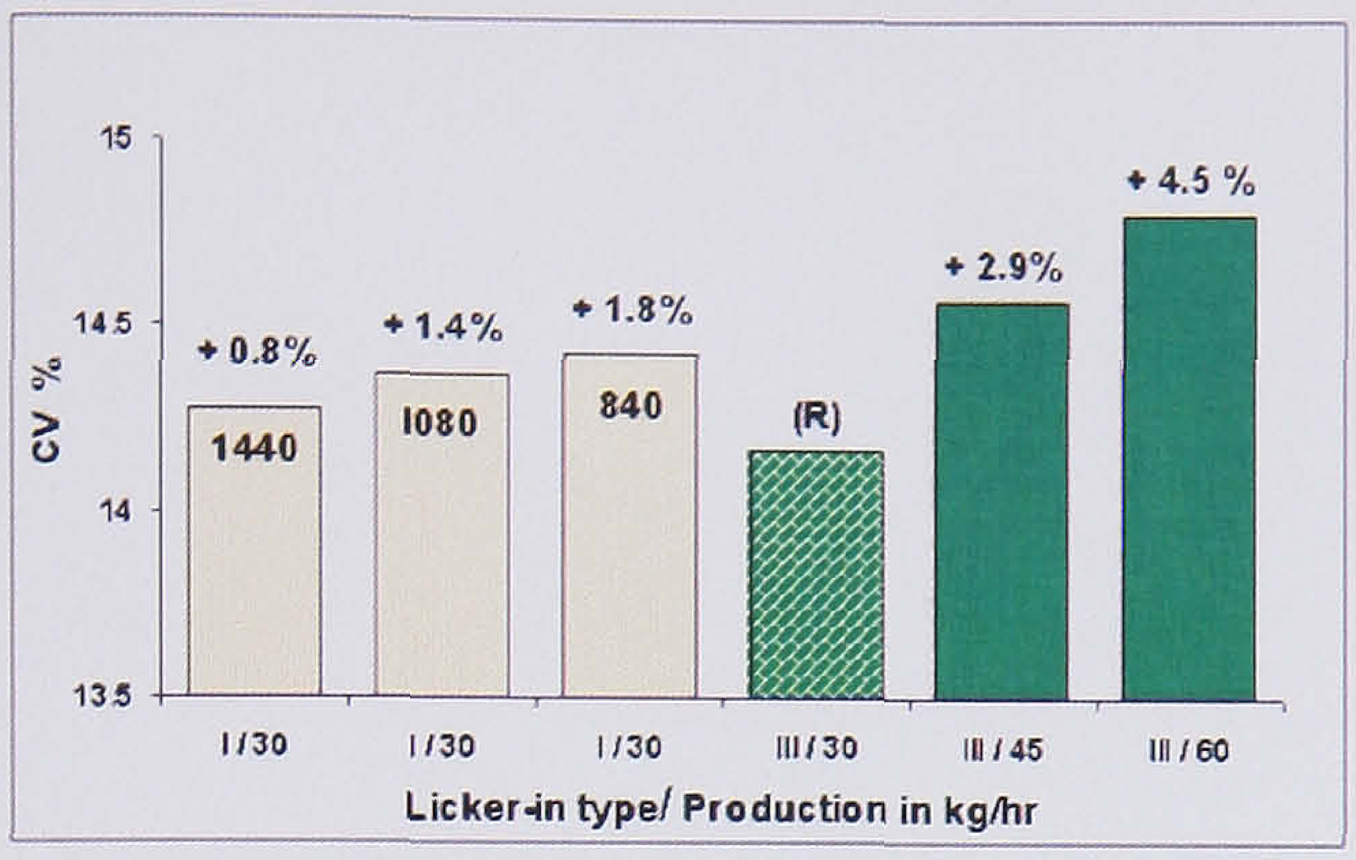


Figure 3.18: Ne 20s - Yarn CV %

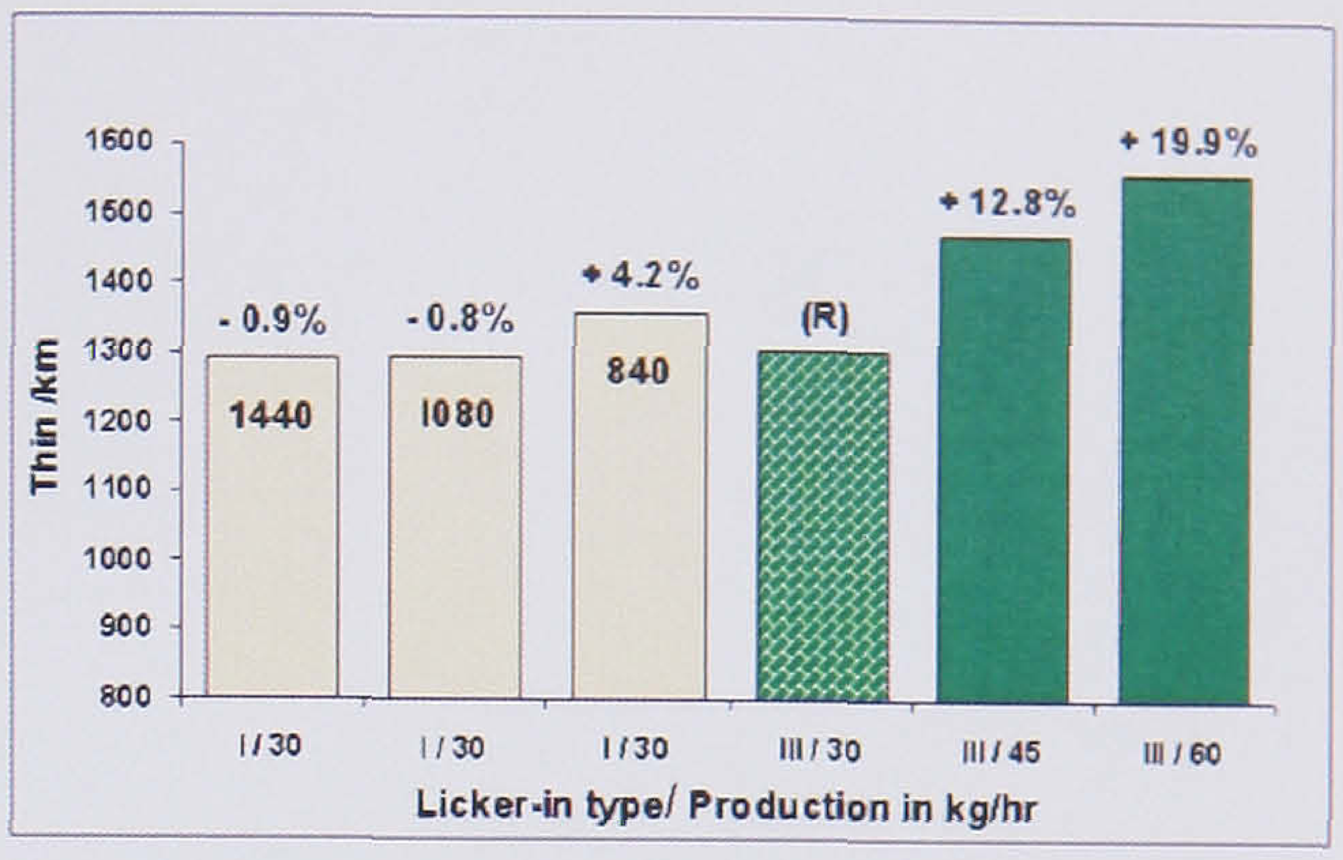


Figure 3.19: Ne 20s - Yarn thin places

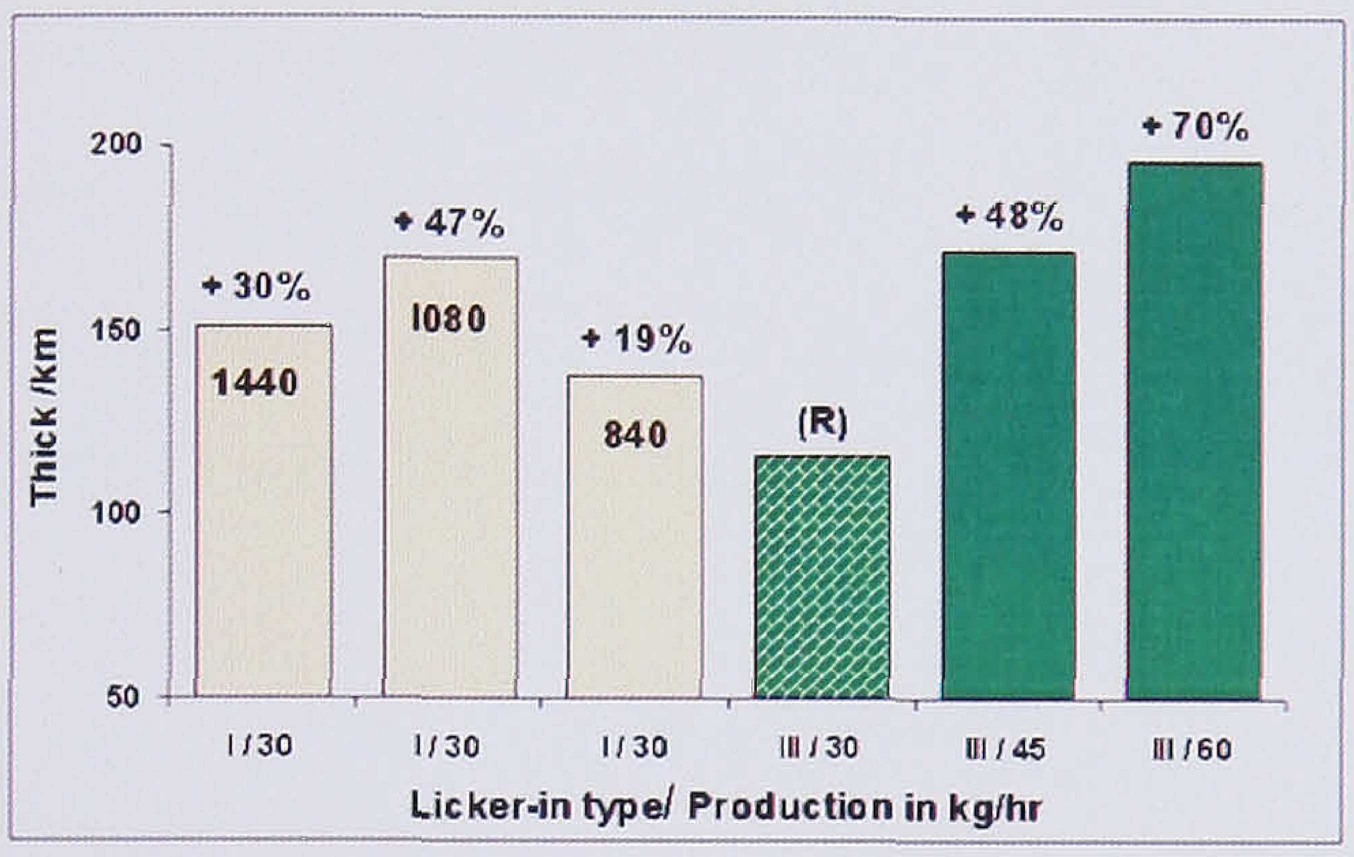


Figure 3.20: Ne 20s - Yarn Thick Places

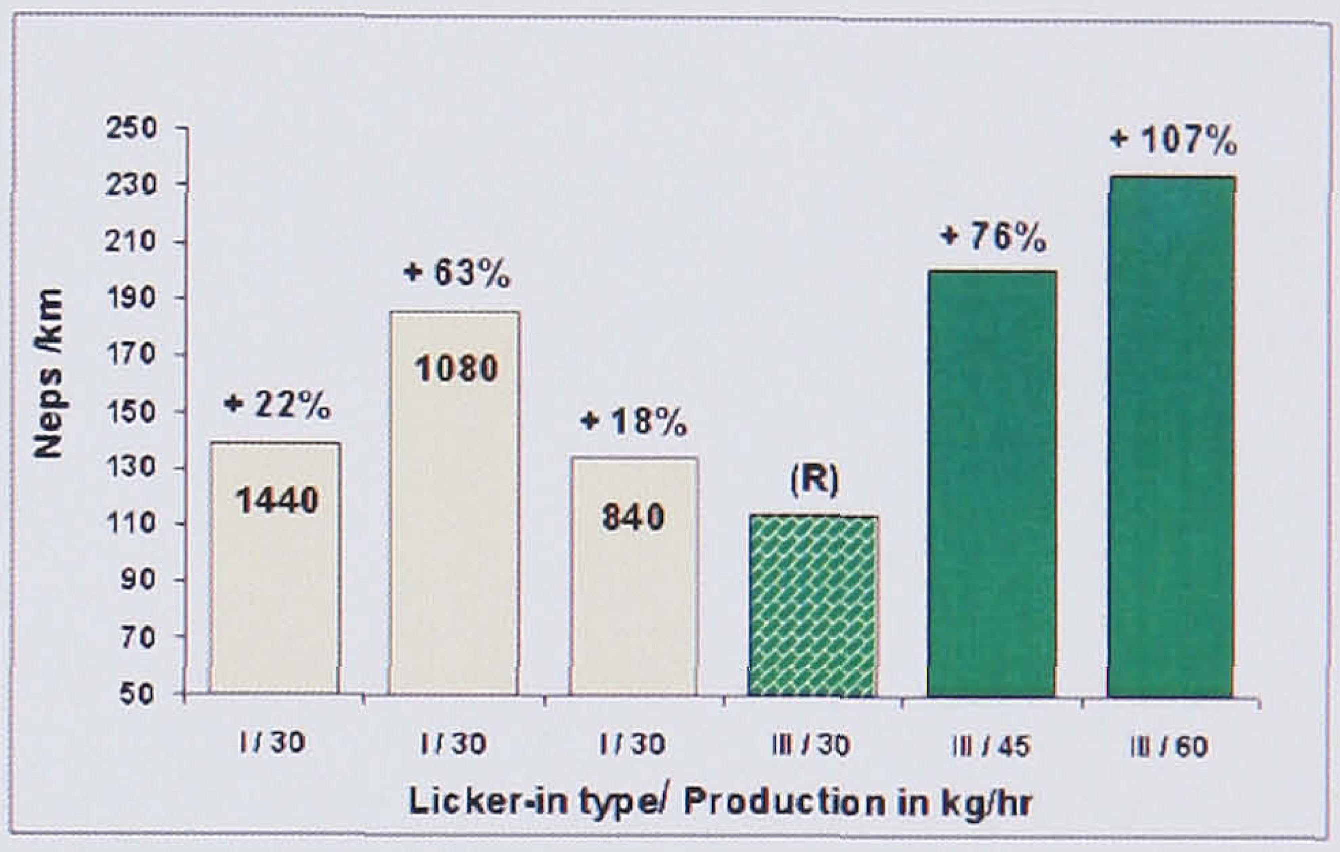


Figure 3.21: Ne 20s - Yarn Neps

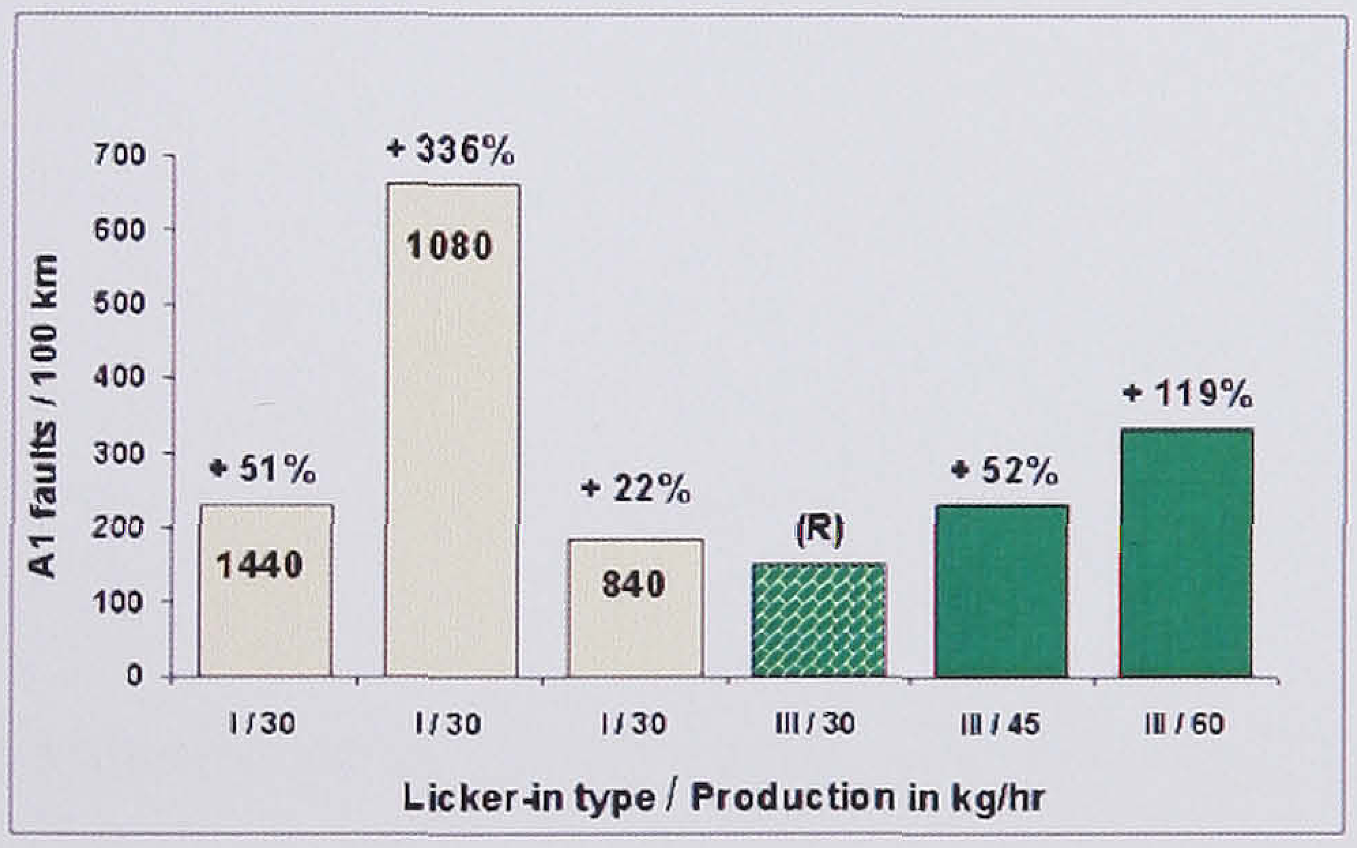


Fig. 3.22: Ne 20s-Yarn Classimat 'A1' faults

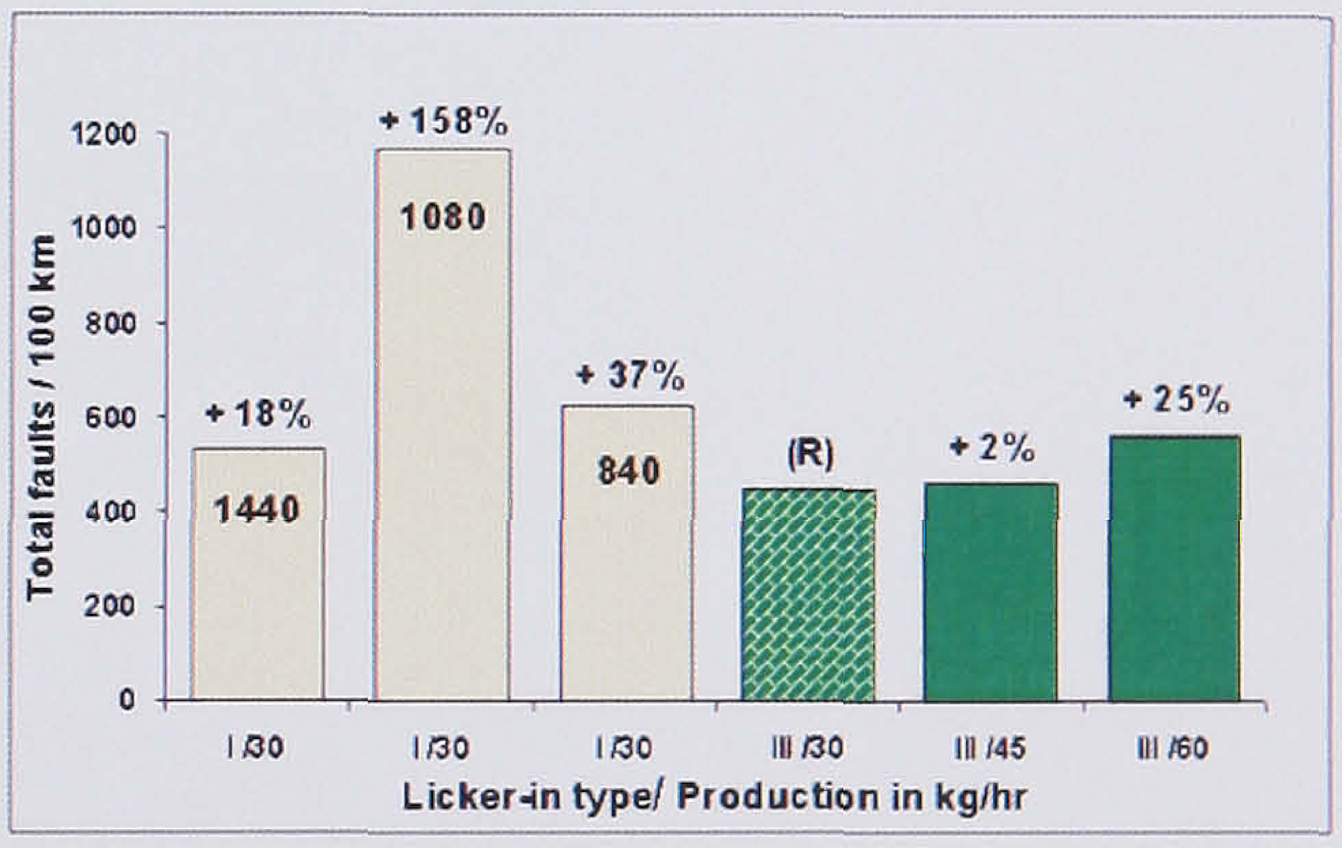


Fig. 3.23: Ne 20s-Yarn Total Classimat faults

The yarn strength and elongation (Figures 3.24 and 3.25) seem to reduce with a reduction in licker-in speed for single licker-in. No particular trend for triple licker-in can be seen with a change in production rate as far as single yarn RKM (Reiss Kilo Meter) is concerned. The yarn elongation with the triple licker-in yarn is significantly better than the single licker-in yarn at all production rates. As the production rate increases, there appears to be a small reduction in yarn elongation with the triple licker-in system.

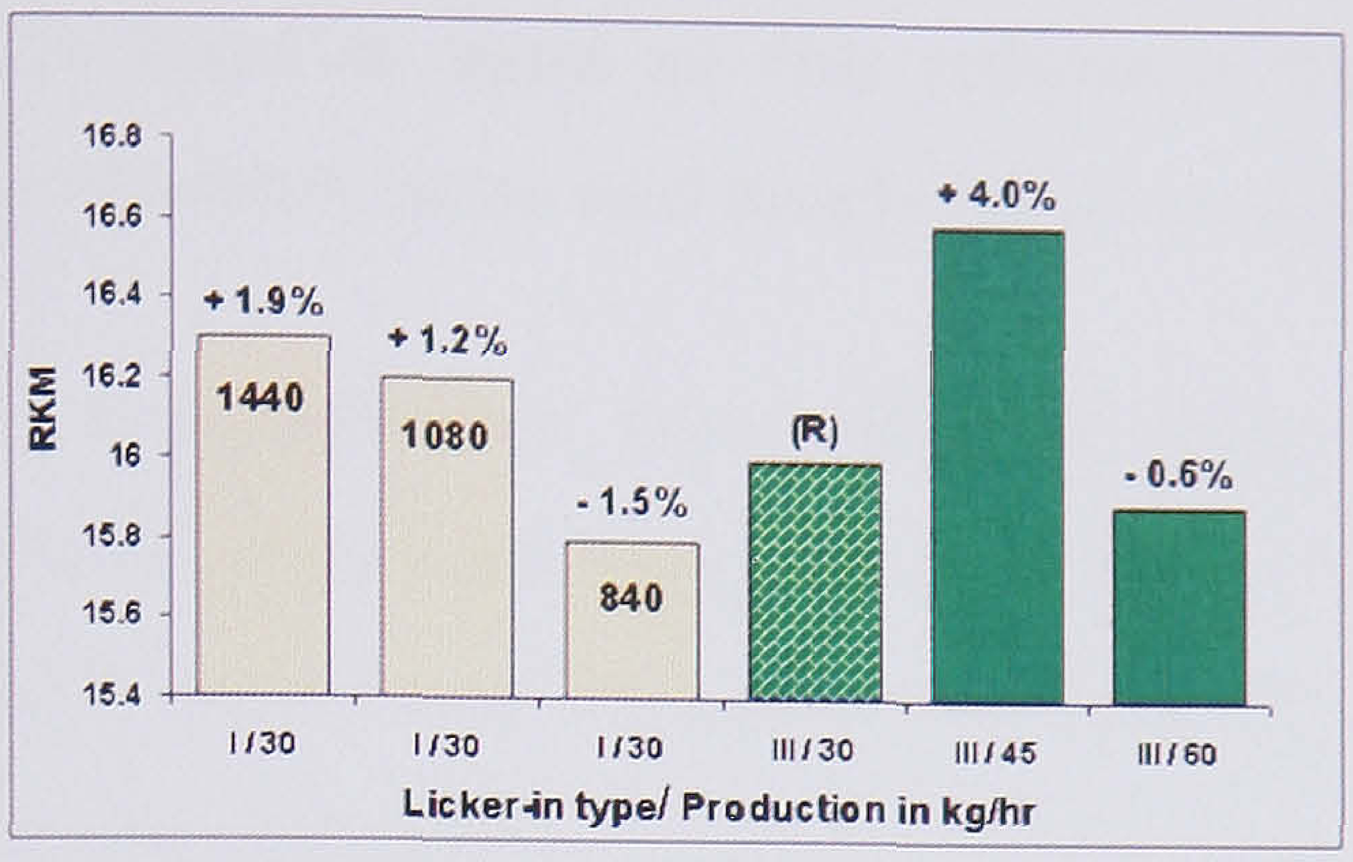


Figure 3.24: Ne 20s - Yarn RKM

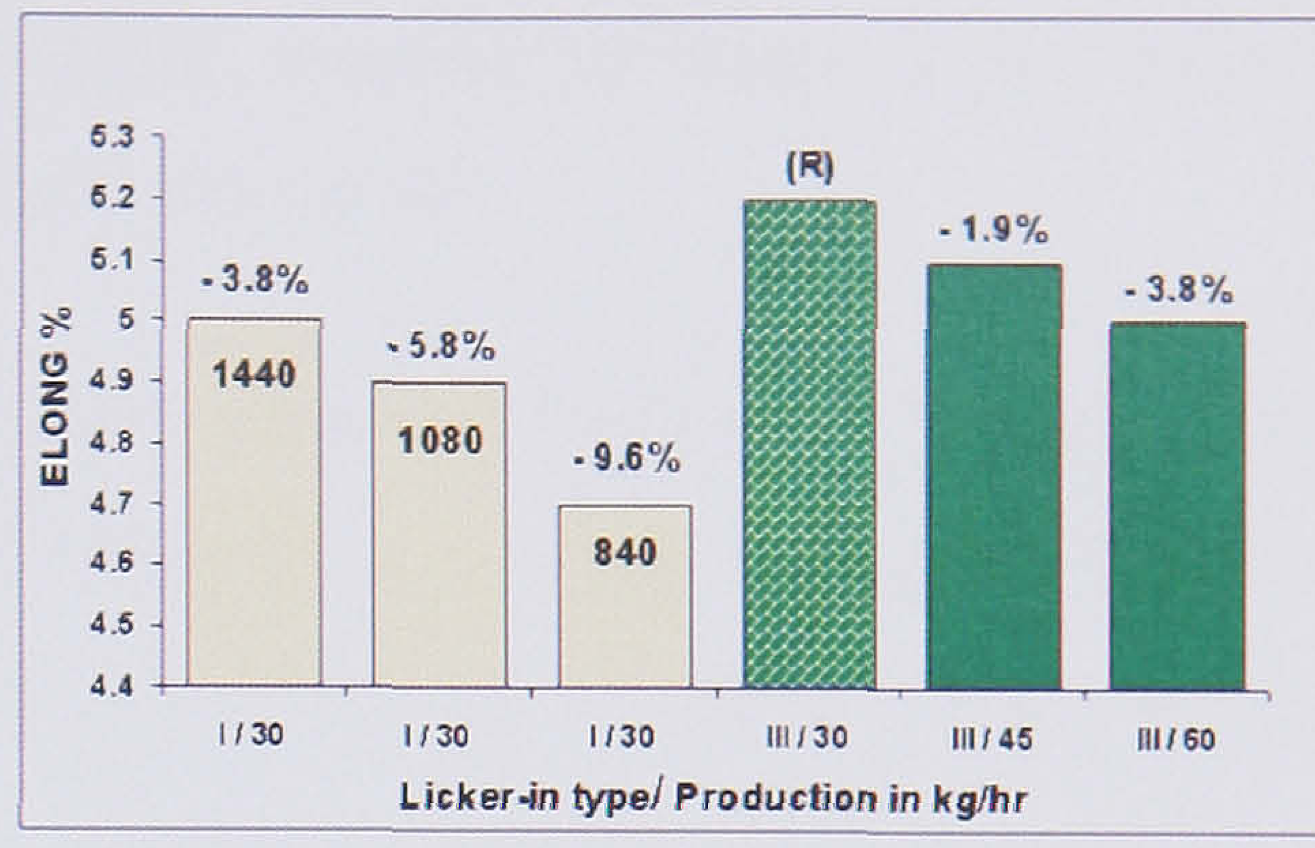


Figure 3.25: Ne 20s - Yarn Elongation %

Yarn hairiness results are shown in figure 3.26. As the production rate increases, there appears to be a reduction in hairiness with the triple licker-in arrangement. With the single licker-in arrangement, the hairiness seems to decrease with a reduction in licker-in speed.

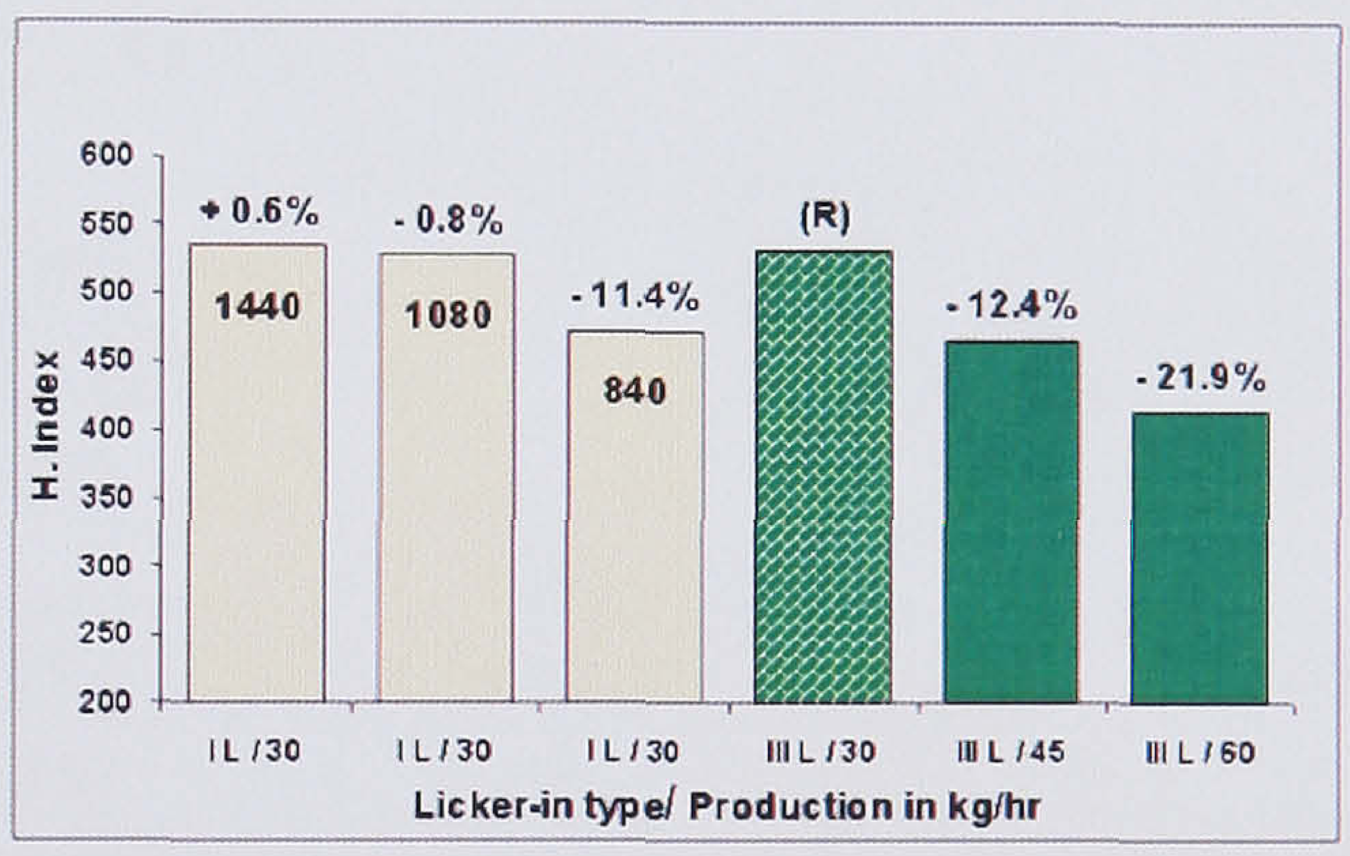


Figure 3.26: Ne 20s - Yarn Hairiness

Statistical significance of the results:

The main feature of the experimental work was to observe the trends when the licker-in or production parameters are varied. Hence, if there were noticeable trends in the results, it could be assumed that the results are significant. Most of the testing (fibre and yarn) was carried out at SITRA's testing laboratories, which is an independent body by their technicians. Because of the small sample size used (5 or 10 tests) for many quality studies, it was unrealistic to expect clear significance statistically. However, 't' tests were carried out for the most important fibre and yarn results to see if some of these results are significantly different. The statistical significance of the results is given in Table 3.8. Triple licker-in at 30 kg per hour is used as the reference from which quality at other triple licker-in production rates and single licker-in speeds is compared.

The significance tests showed that the fibre quality in terms of neps, yarn irregularity and imperfections with triple licker-in were significantly different (at 95% confidence levels) from that of single licker-in and other triple licker-in production rates.

Table 3.8: Statistical significance of the quality results for Ne 20s (NHH 44)

STATISTICAL SIGNIFICANCE (Reference-Triple licker-in at 30 kg/hr)						
Machine Parameters						
Number of Licker-ins	TL	TL	TL	SL	SL	SL
Licker-in speed (rpm)	*	*	*	1440	1080	840
Production rate (kg/hr)	30	45	60	30	30	30
Fibre Quality (Card sliver)						
AFIS SFC (w)%	R	CS	NS	NS	NS	NS
AFIS Mean Length	R	CS	NS	NS	NS	NS
AFIS Neps	R	S	S	S	S	S
Yarn Quality						
Uster CV%	R	S	S	NS	CS	S
Thin (-30%)	R	S	S	NS	NS	NS
Thick (50%)	R	S	S	S	S	S
Neps (+200%)	R	S	S	S	S	S
Yarn Strength (RKM)	R	CS	NS	CS	NS	CS
Yarn Elongation %	R	CS	S	S	S	S
Zweigle Hairiness Index	R	NS	S	NS	NS	CS

* Note: The triple licker-in speeds (rolls 1, 2, 3) were 998, 1568, and 2067 respectively.

R	**Reference Case**	
NS	**Not Significant**	
S	**Significant**	(yellow)
CS	**Closer to 95% significance levels**	(grey)

3.3.2.2 Fine ring spun yarn results

As can be seen from Figs 3.27 to 3.34, the yarn irregularity (CV%), thin and thick places, neps, Classimat 'A1' and Classimat total faults are greater with the triple licker-in system compared to the single licker-in yarns and increase greatly with an increase in production rate. The overall quality in terms of uniformity, imperfections and Classimat faults is good at the speed of 840 rpm for the single licker-in system. In Figs 3.27 to 3.35, the triple licker-in at 10 kg/hr has been used as the reference (indicated by the letter 'R') from which the quality changes with the single and triple licker-in parameters are compared.

Note:

1) I and III refer to single and triple licker-in respectively.
2) The triple licker-in speeds in rpm (rolls 1,2,3) were 755, 1202 and 1516 respectively.
3) Percentages are given with respect to the reference case (R) i.e. Triple licker-in at 10 kg/hr.

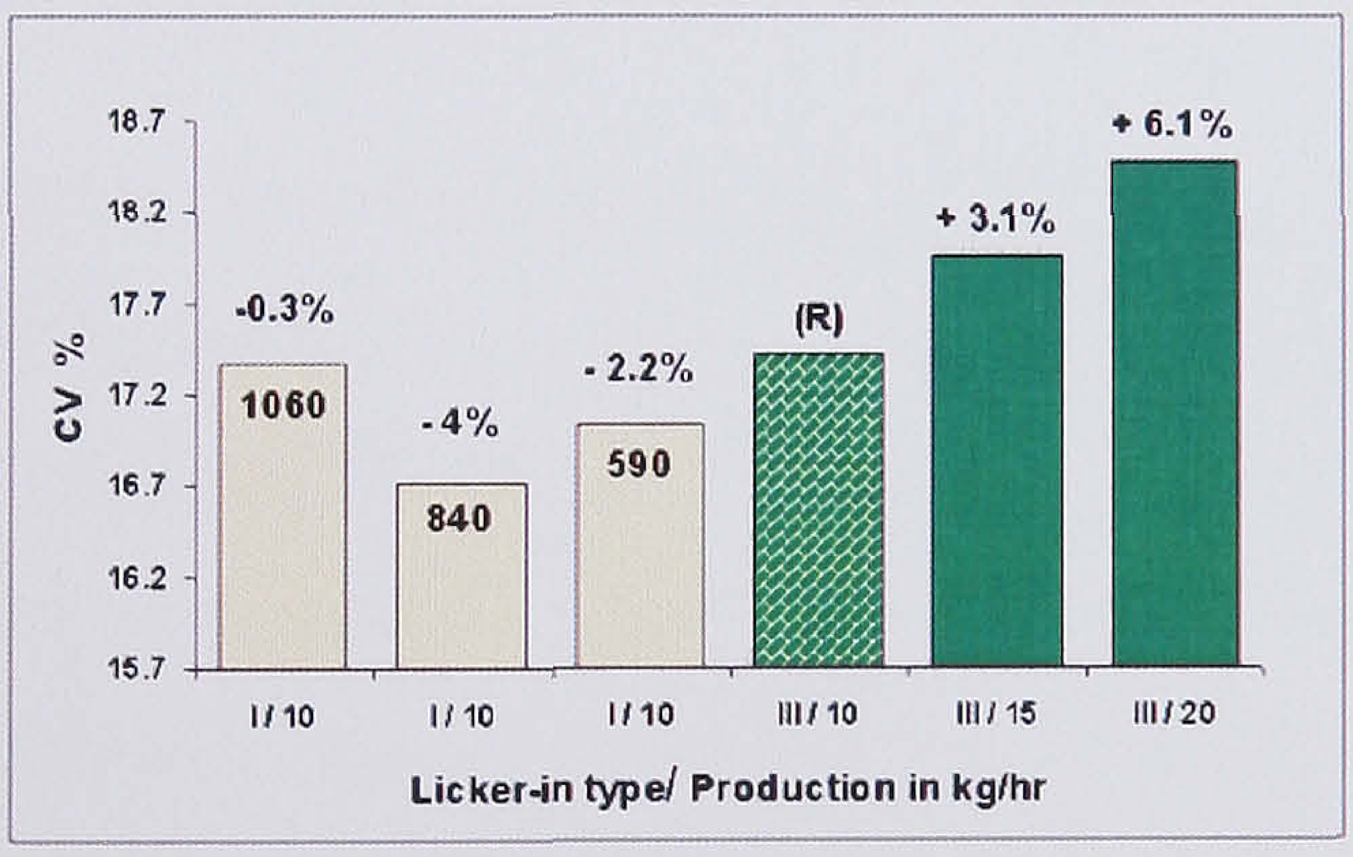


Figure 3.27: Ne 80s - Yarn CV

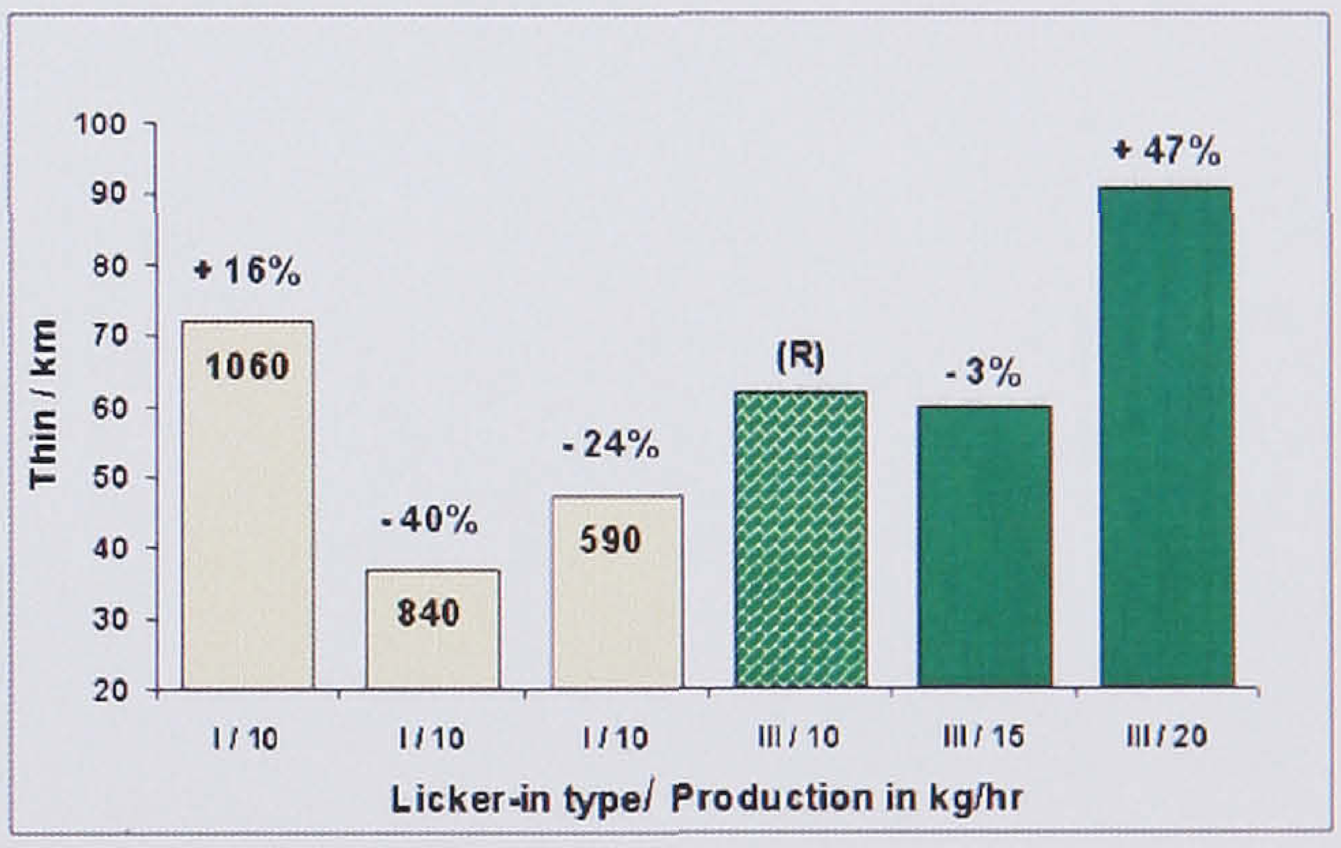


Figure 3.28: Ne 80s - Yarn Thin Places

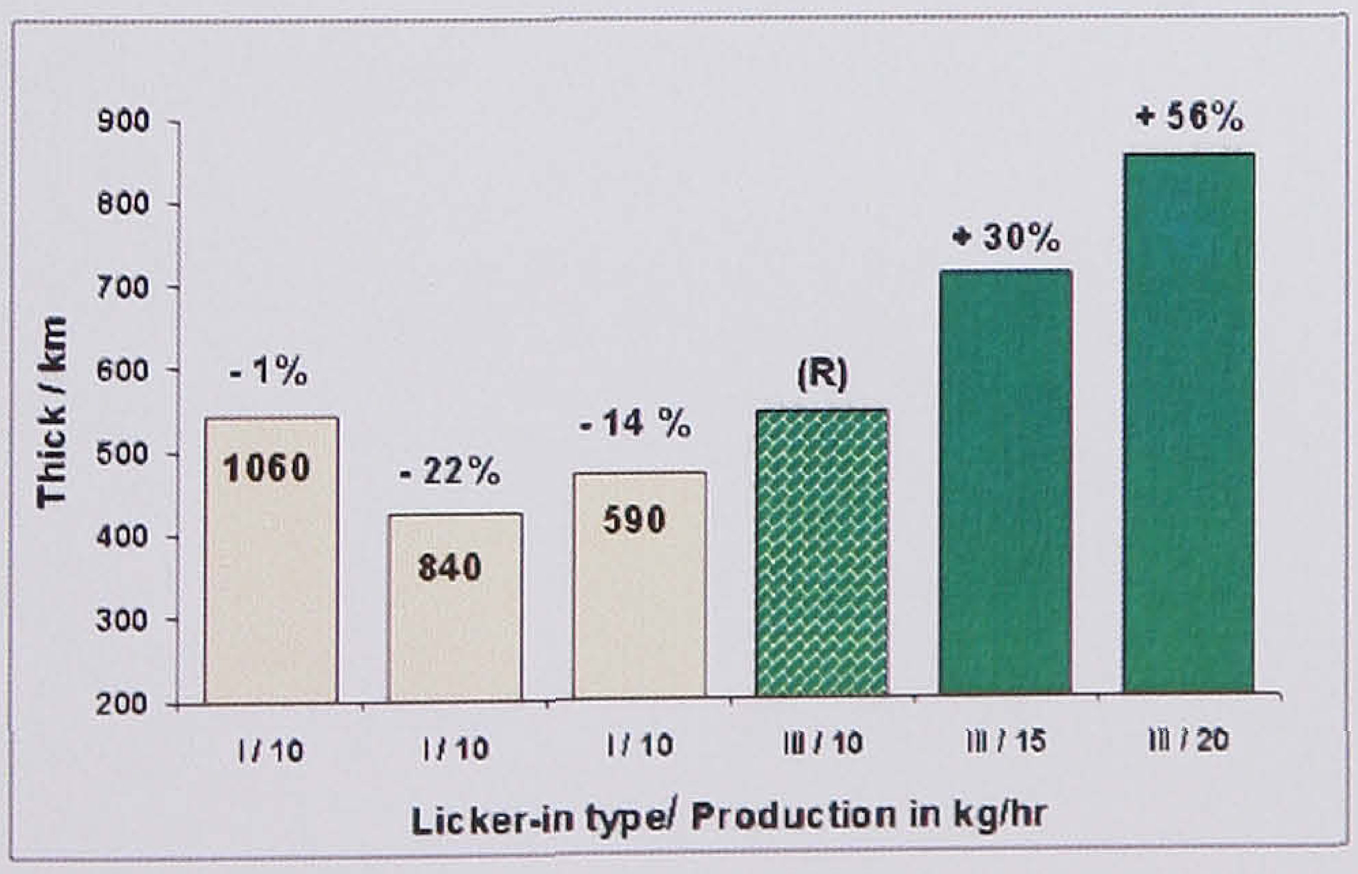


Figure 3.29: Ne 80s - Yarn Thick Places

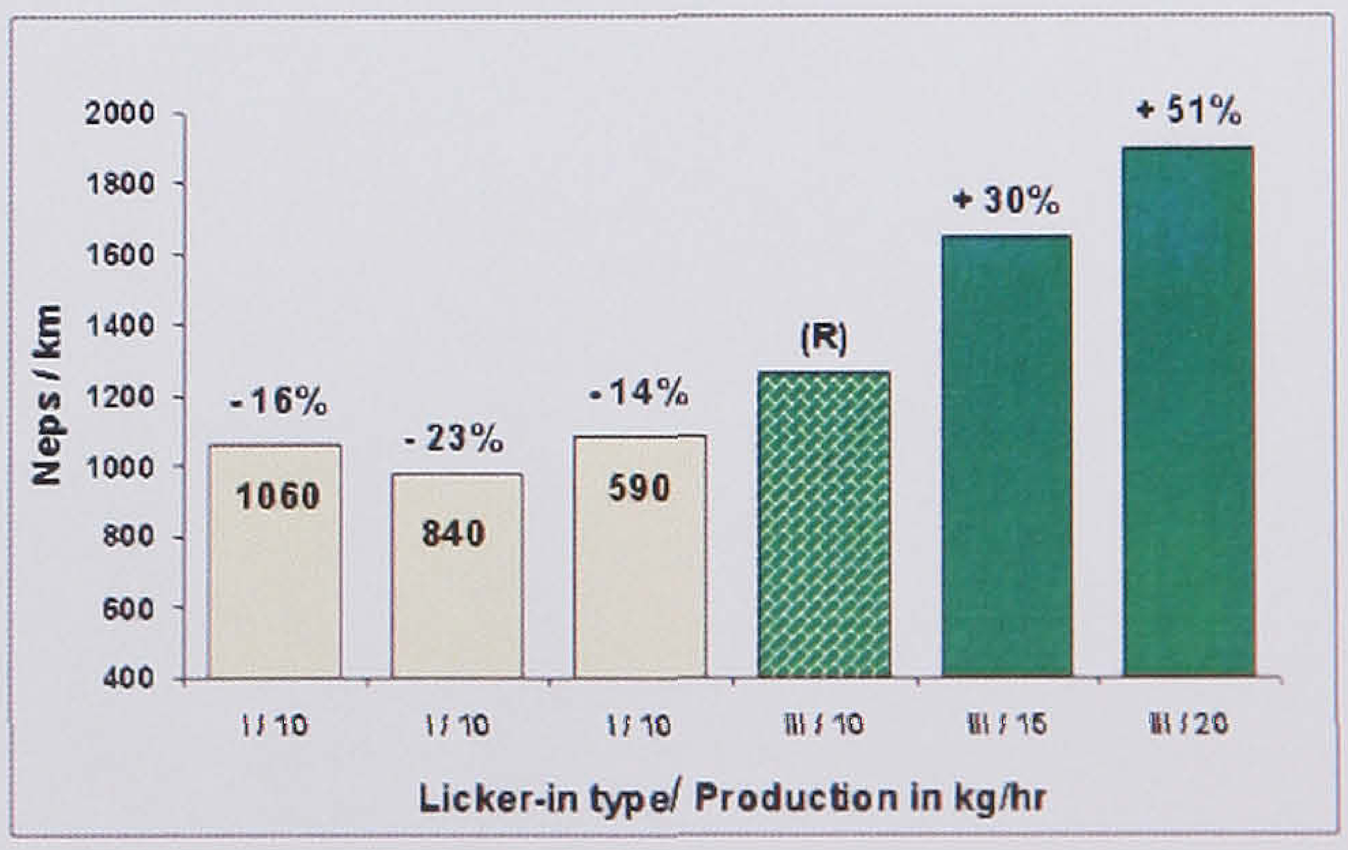


Figure 3.30: Ne 80s - Yarn Neps

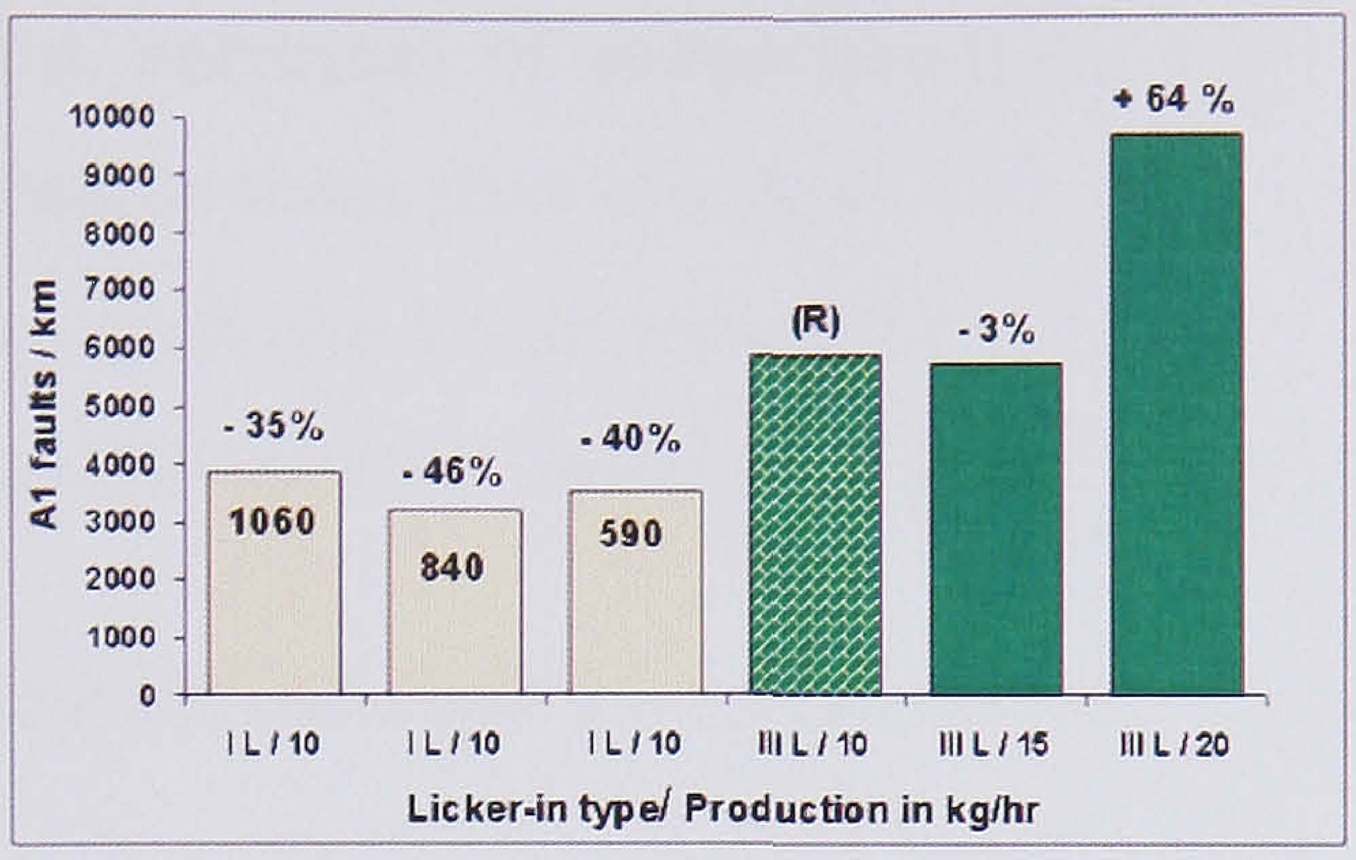


Fig. 3.31: Ne 80s-Yarn Classimat 'A1' faults

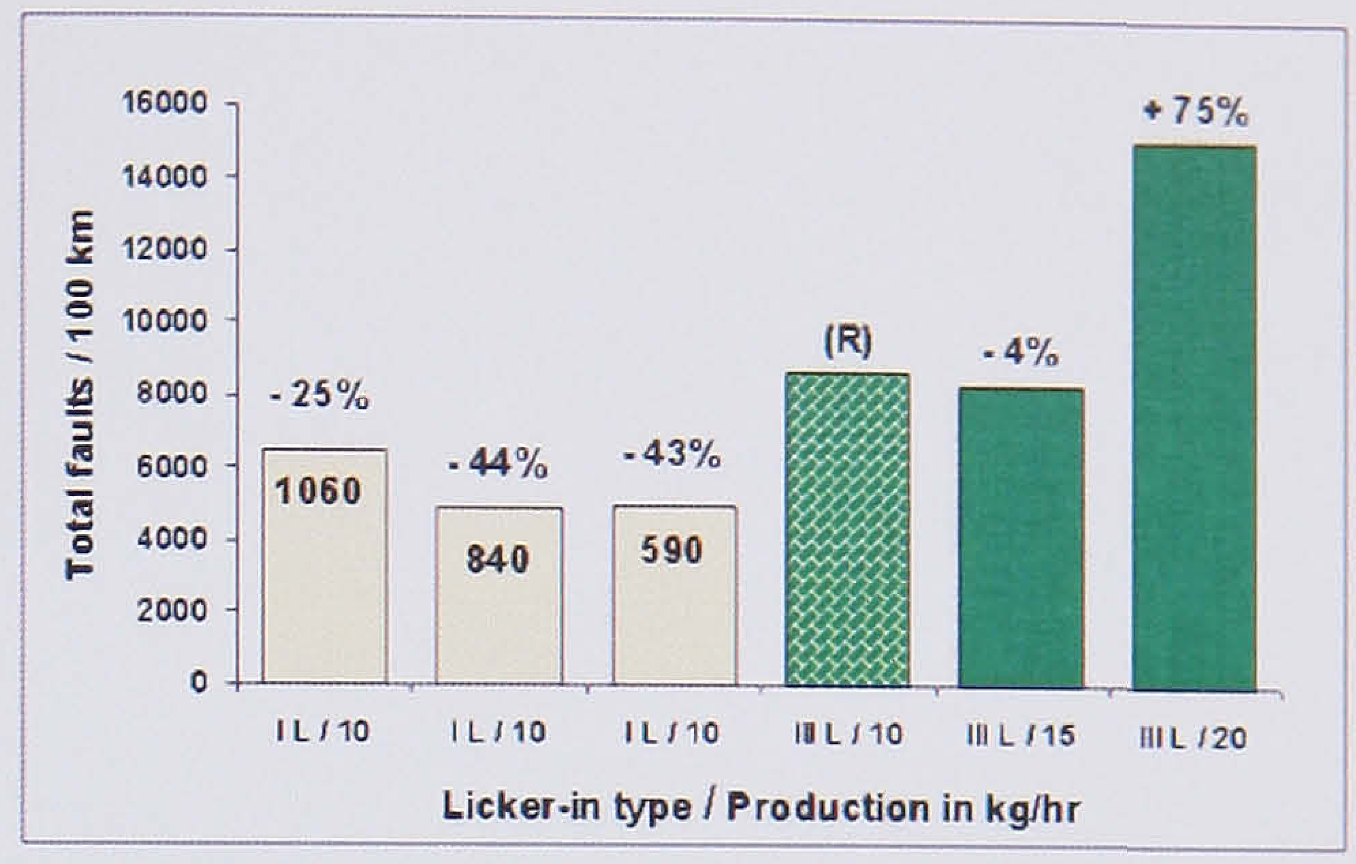


Fig. 3.32: Ne 80s-Yarn Total Classimat faults

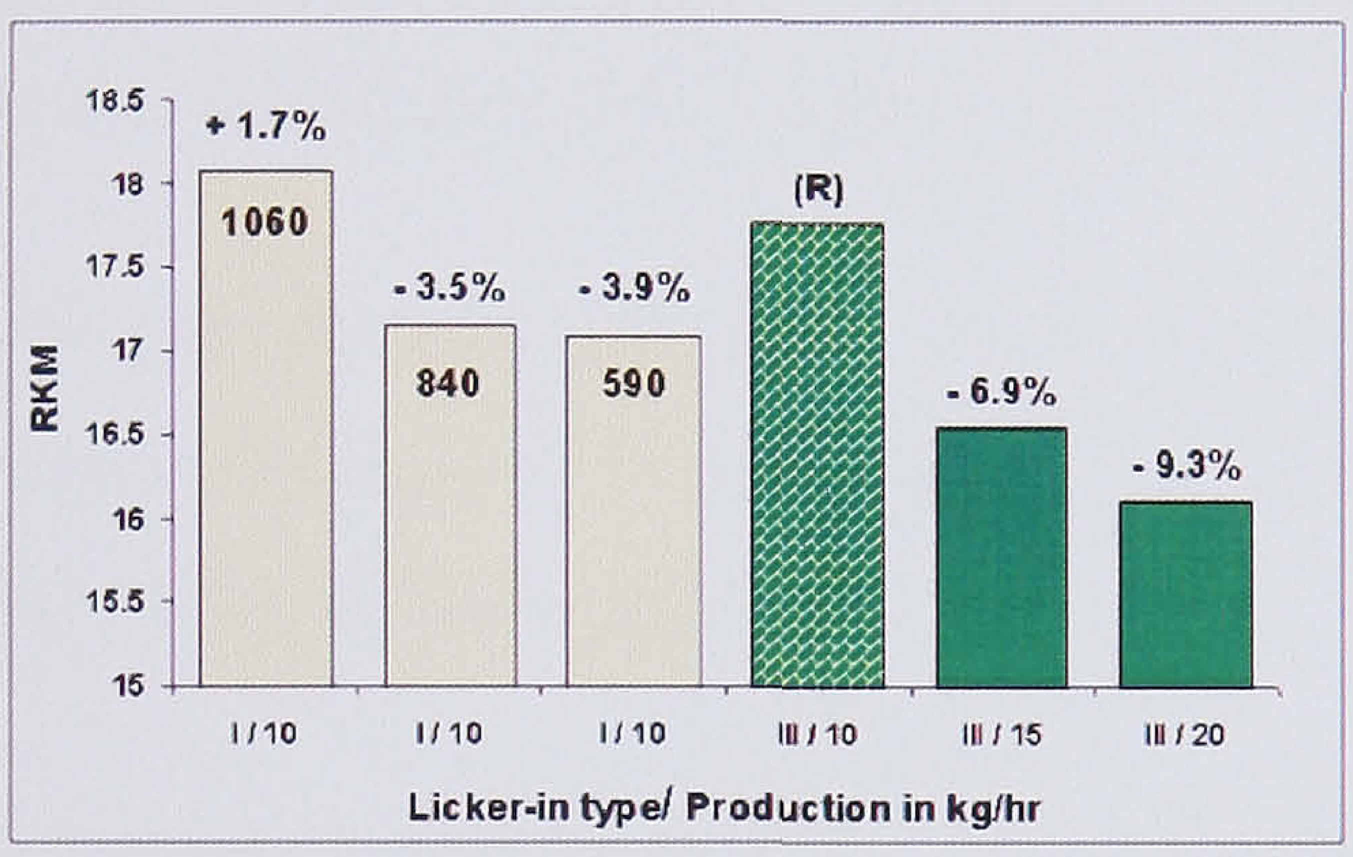


Figure 3.33: Ne 80s - Yarn RKM

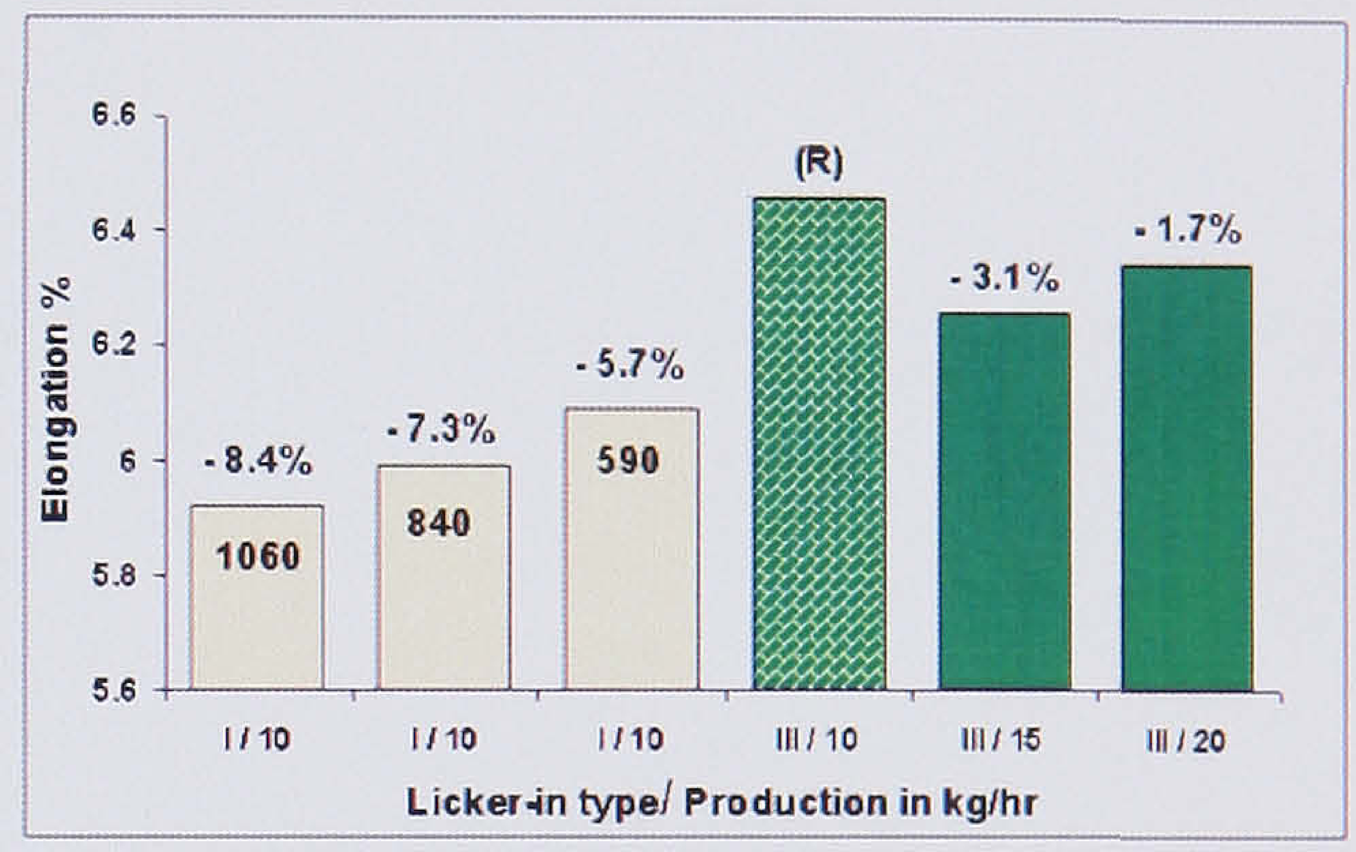


Figure 3.34: Ne 80s - Yarn Elongation %

As can be seen from figure 3.34, a clear trend is visible showing a reduction in RKM as far as triple licker-in system is concerned, when the production rate is increased. While yarn strength shows a trend of increasing with an increase in licker-in speed, the elongation (Figure 3.35) is shown to decrease, for the single licker-in system. The yarn elongation however, is better with the triple licker-in system at all production rates than with the single licker-in system.

Yarn hairiness results with Zweigle 566 tester are shown in Fig 3.35.

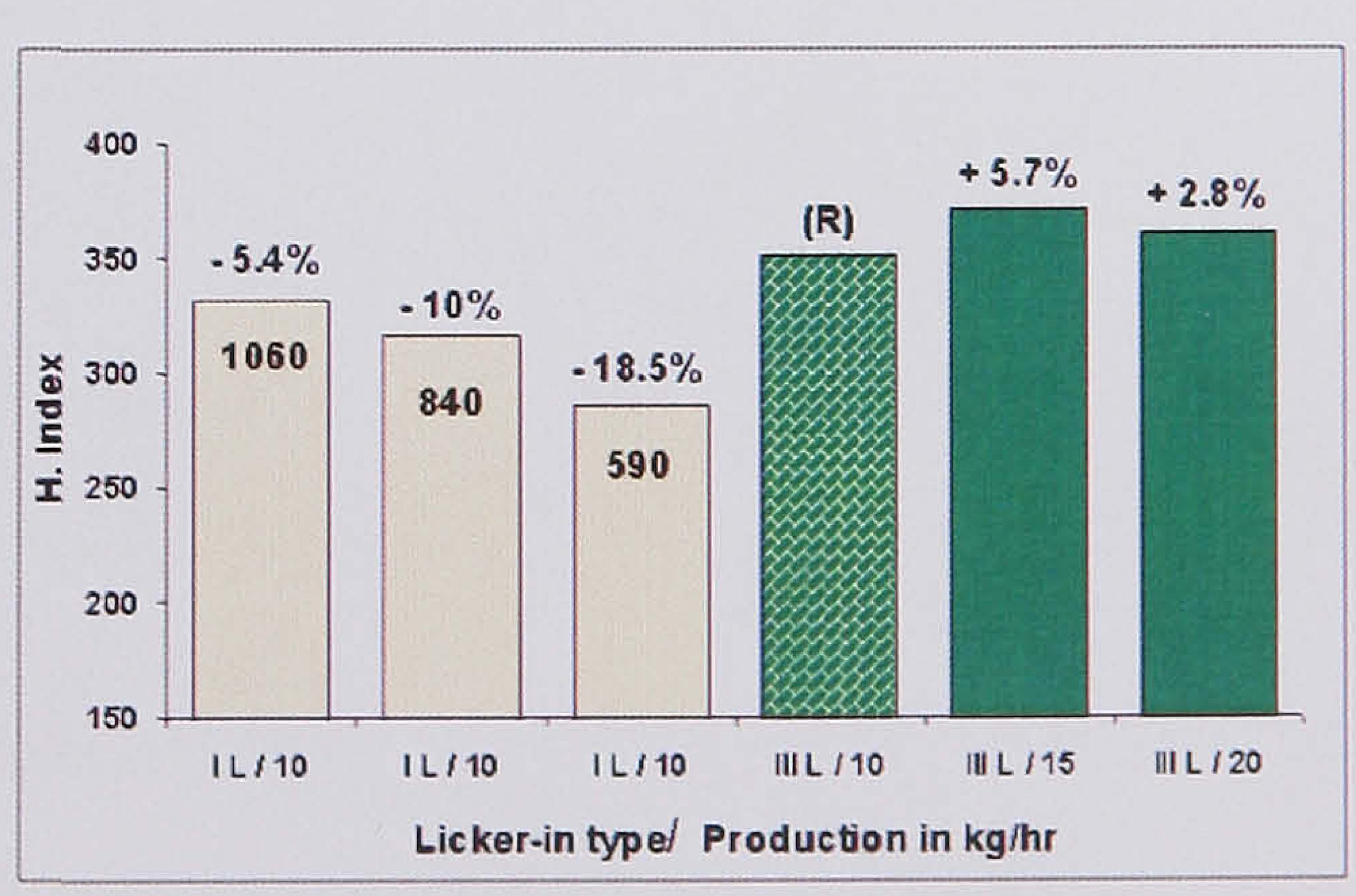


Figure 3.35: Ne 80s - Yarn Hairiness

The hairiness of yarns produced with the triple licker-in system appears to be greater than that of single licker-in yarns at all production rates without showing any definite trend in production rate. As for the coarse yarn, the yarn hairiness decreases when the single licker-in speed is decreased.

Statistical significance of the results:

The statistical significance of the results is given in Table 3.9. Triple licker-in at 10 kg per hour was again used as the reference from which other triple licker-in production rates and single licker-in speeds are compared.

The significance tests showed that the fibre quality in terms of neps, mean length, yarn irregularity and imperfections with triple licker-in were significantly different from that of the single licker-in.

Table 3.9: Statistical significance of the quality results for Ne 80s (DCH 32)

STATISTICAL SIGNIFICANCE (Reference-Triple licker-in at 10 kgs /hr)						
Machine Parameters						
Number of Licker-ins	TL	TL	TL	SL	SL	SL
Licker-in speed (rpm)	**	**	**	1080	840	590
Production rate (Kgs /hr)	10	15	20	10	10	10
Fibre Quality (Card Sliver)						
AFIS SFC (w)%	R	NS	NS	CS	S	NS
AFIS Mean Length	R	NS	NS	CS	CS	NS
AFIS Neps	R	S	S	S	PS	S
Yarn Quality						
Uster CV%	R	S	S	NS	S	S
Thin (-50%)	R	NS	S	NS	S	CS
Thick (+50%)	R	S	S	NS	S	NS
Neps (+200%)	R	S	S	S	S	S
Yarn Strength (RKM)	R	NS	S	S	NS	NS
Yarn Elongation %	R	CS	NS	S	S	S
Zweigle Hairiness Index	R	NS	NS	NS	NS	CS

** The Triple licker-in speeds (rolls 1,2,3) were 755, 1202 and 1516 respectively

R	**Reference Case**
NS	**Not Significant**
S	**Significant**
CS	**Closer to 95% significance levels**

3.3.3 Fabric Assessments

3.3.3.1 Knitted Fabric Appearance

The results are given in Appendices 15 and 16. Ten judges from South India Textile Research Association evaluated the knitted fabrics for their appearance in terms of regularity and cleanliness. Results of the evaluations were analysed statistically to determine the degree of agreement using the method explained in Chapter 2, Section 2.6.2. The parameter 'Coefficient of Concordance' indicates the degree of agreement. The higher the value, the better is the agreement among the judges.

a) Coarse yarn knitted fabric appearance

Table 3.10: Coarse Yarn Knitted Fabric Rankings (Ne 20s)

	Single licker-in			Triple licker-in		
	1440 rpm	1080 rpm	840 rpm	30 kg/hr	45 kg/hr	60 kg/hr
Regularity	6	1	2	3	4	6
Cleanliness	5	2	3	1	4	6

Except for single licker-in results at 1440 rpm and triple licker-in results at 60 kg/hr, which were ranked the worst, the judges had difficulty in ranking the fabrics and were not in good agreement especially for rating the regularity (Coefficient of Concordance values for Regularity - 0.37 and Cleanliness - 0.62). It is however clear that single licker-in at 30 kg per hour produced a more even fabric than triple licker-in at the same production rate, even though the triple licker-in yarn was better in quality. The appearance grades with single licker-in at 840 rpm, 1080 rpm and triple licker-in at 30 kg per hour were close to each other. Higher single licker-in speed as well as higher production rate with triple licker-in resulted in poor fabric appearance.

b) Fine yarn knitted fabric appearance

Table 3.11: Fine Yarn Knitted Fabric Rankings (Ne 80s)

	Single Licker-in			Triple Licker-in		
	1080 rpm	840 rpm	590 rpm	10 kg/hr	15 kg/hr	20 kg/hr
Regularity	2	3	5	1	6	4
Cleanliness	2	3	4	1	6	5

In the case of finer yarn knitted fabrics, the judges were in closer agreement (Coefficient of Concordance values for Regularity – 0.789 and Cleanliness – 0.747). Interestingly the triple licker-in at 10 kg/hr produced a more even fabric than the single licker-in, even though in terms of yarn quality it was inferior to the single licker-in. Single licker-in produced fabric with better appearance at the highest speed of 1080 rpm. Decreased speeds of single licker-in or higher production rates with triple licker-in produced inferior fabrics. It is also surprising that the best yarn in terms of evenness and imperfections (single licker-in at 840 rpm) produced a fabric, which is only the third best in terms of regularity and cleanliness.

3.3.3.2 Fabric Pilling Tendency

Figure 3.36 shows the results of fabric pilling tests carried out on 20s Ne yarn.

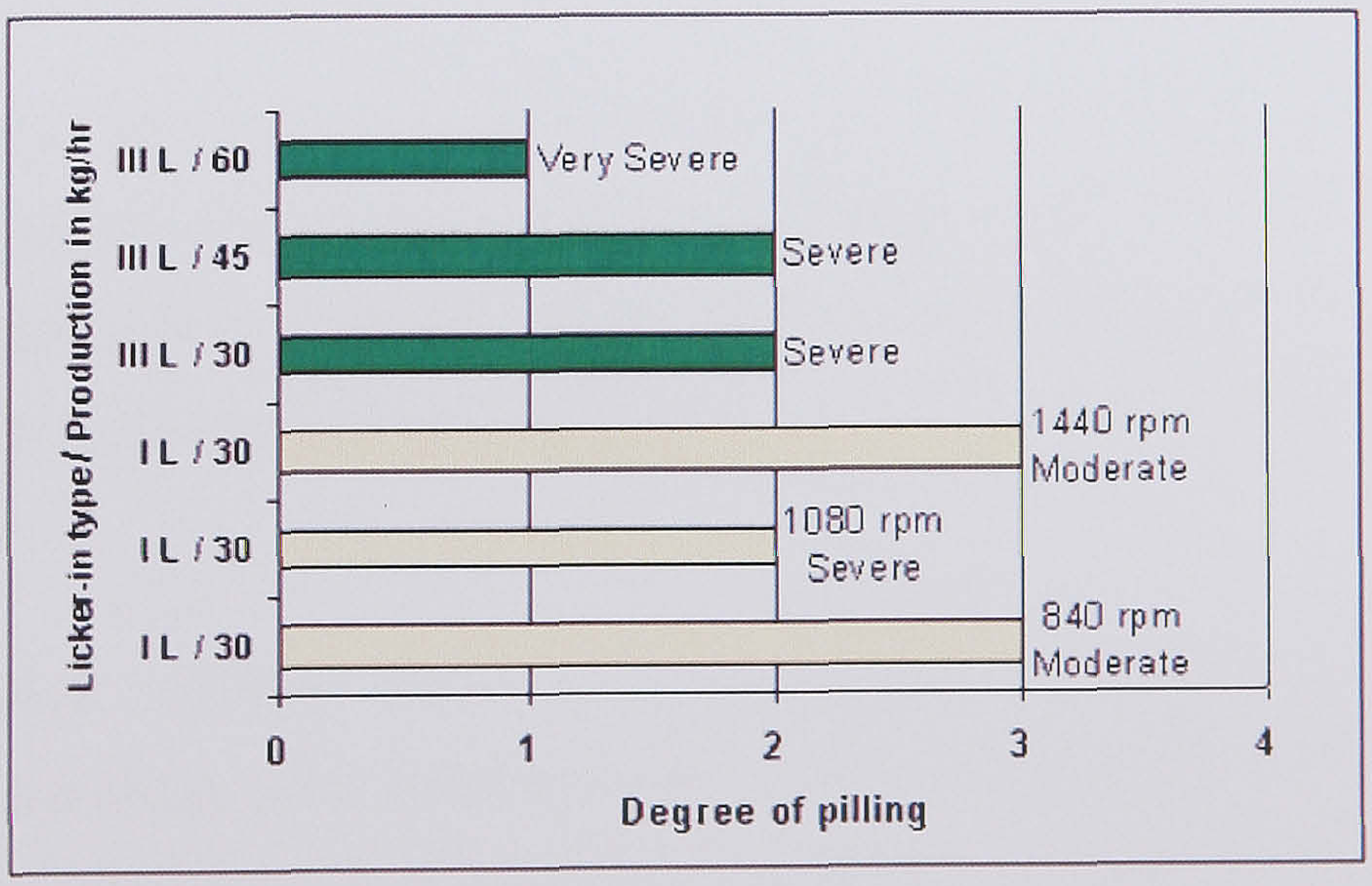


Figure 3.36: Ne 20s - Pilling Results

Note: Degree of pilling grade 1 refers to very severe pilling and grade 4 refers to low degree of pilling

For 20s Ne yarn, the grading tests after pilling indicate that pilling is severe with the fabrics produced with the triple licker-in slivers. The pilling is severe to very severe for the triple licker-in in spite of slightly lower hairiness values than single licker-in, whereas it is moderate to severe for single licker-in. However, results of 80s Ne show that the pilling tendency is the same for fabrics made with both the single and the triple licker-in yarns. All the fabrics (single & triple) show the same amount of pilling tendency (categorised as severe), in spite of the triple licker-in yarns having greater hairiness values.

3.4 Summary and Conclusions

The fibre, yarn and fabric quality results obtained using the single licker-in and the triple licker-in systems have been discussed in this chapter. The influence of the licker-in arrangements on some important aspects of fibre, yarn and fabric quality was tested. Experiments were conducted on a Crosrol card, which is designed to work with a single licker-in. Since it was converted to accommodate a three licker-in system, the findings of the study can only be taken to indicate the broad trends in quality. In particular, these conclusions cannot be taken to apply wholly to other commercial triple licker-in systems, which may have design parameters optimised for better performance.

The study was a controlled one with the number of variables reduced to as few as possible. Each cotton was perfectly blended and processed through the same set of machines, spindles etc., from blow-room to spinning and so the final results are considered fully reflective of the actual carding performance with the two licker-in arrangements.

The experiments showed there is a significant decrease in fibre length or alternatively speaking fibre breakages occurred with both licker-in systems when processing the long and fine DCH 32 cotton. Neps also increased dramatically in the licker-in zone with both licker-in systems. There is a clear indication that in order to save fibre length and decrease waste, licker-in speeds should be at an optimum. In general, for both DCH 32 and NHH 44 cotton varieties, the over-all quality in terms of uniformity, imperfections, Classimat faults and knitted fabric appearance was better at 840-rpm single licker-in speed. From the fibre and yarn test results obtained, the triple licker-in system produced better quality yarn (about 20% less imperfections and 20% less Classimat faults compared to the best single licker-in yarn) when processing the shorter cotton at the same production rate as single licker-in. Clearly the triple licker-in system appears to have an advantage when processing shorter cotton and hence an increase in production should be possible with the triple licker-in system. For the long DCH 32 fibres, at the same production rate as triple licker-in, the single licker-in produced better quality results, especially from the point of view of fibre neps, sliver trash and yarn quality (about 25% less imperfections and 40% less Classimat faults compared with the best single licker-in yarn). With the triple licker-in, deterioration in quality is noticed as the production rate is further increased. As far as short fibre content in sliver or mean fibre length is concerned, the triple licker-in system seems to be on par with the single licker-in for both the NHH 44 and the DCH 32 cotton. Another interesting finding is that the appearance grades of knitted fabrics with single and triple licker-in systems are not entirely in agreement with the yarn quality results. The fabric-pilling tendency is found to be greater with the triple licker-in for NHH 44 (medium, average fineness) cotton.

Interestingly, the hairiness of the yarns also seems to be influenced by the licker-in parameters/design. A clear trend that is seen is the reduction of hairiness of yarns with a decrease in licker-in speed for both cotton varieties with single licker-in. Triple licker-in processed material shows higher hairiness values than single licker-in (at the optimum licker-in speed of 840 rpm) at the same production rates for both cotton varieties. The differences in hairiness values could be an indicator that the fibre arrangement within the yarn is influenced to a certain degree by the licker-in parameters/design.

The overall results appear to substantiate the anecdotal evidence in the industry about the triple licker-in system being less successful in processing finer or longer fibres. It appears that the triple licker-in design has certain shortcomings in the processing of long and delicate fibres, and further research is required to determine its causes.

It is quite possible that the transfer of fibres between the licker-in rollers is not properly achieved, causing the fibres to cycle repetitively on the licker-in surfaces, which could prove detrimental for the fine long fibres such as Indian DCH 32. It is also possible that a certain degree of nipped opening is lost with a triple licker-in arrangement at the feed roller nip/ first licker-in, due to the low speeds of the first licker-in roller.

Because of the complexity of the process, it is difficult to relate the quality results to the fibre dynamics within the licker-in systems and a more systematic examination of the opening process is clearly required. A further investigation would be useful to examine the possible causes that restrain the use of triple licker-in systems in processing fine and long fibres. Such an understanding may eventually lead to a more refined design that can process long and delicate fibres more efficiently.

Since Rimmer [46, 47] reported her observations of the changes in fibre configuration in card web and yarn with the two licker-in designs, an analysis of fibre configuration in yarns has been undertaken in this work. The next chapter will deal with the fibre configuration in yarns with the single and triple licker-in systems.

Chapter 4

Phase II Experimentation: Fibre Configuration in Yarns

4.1 Introduction

Chapter 1 and 3 respectively dealt with the licker-in designs and the impact of two commercial designs, viz. single and triple licker-in designs, on the quality of the yarns spun. It was established in the trials that the quality of the yarns spun are influenced by the design and the degree of opening at the licker-in zone. Changes in yarn hairiness and fabric-pilling tendency indicate that fibre configuration in the yarn could be significantly influenced by the use of different licker-in arrangements. Hence, it was found necessary to study how licker-in design influences fibre configuration in yarns. This Chapter discusses the fibre configuration in yarns spun from fibres carded using the two licker-in systems.

4.2 Methodology

4.2.1 Fibre Processing

All the experiments were carried out, in a production environment, on the same Crosrol Mark 5 High Production Card with single and triple licker-in arrangements. Two Indian cotton varieties with widely differing characteristics were selected and processed on this card with both the licker-in systems (Processes explained in detail in Chapter 2). The cottons were processed separately through the blow-room to spinning after blending with black fibres (0.05%) used to evaluate the fibre configuration, prepared from the respective cotton varieties used for the experiments. Six yarns were spun from fibres carded using each of the two licker-in arrangements and their quality characteristics assessed; the fibre configuration in the same yarns was also studied.

4.2.2 Fibre Configuration Studies

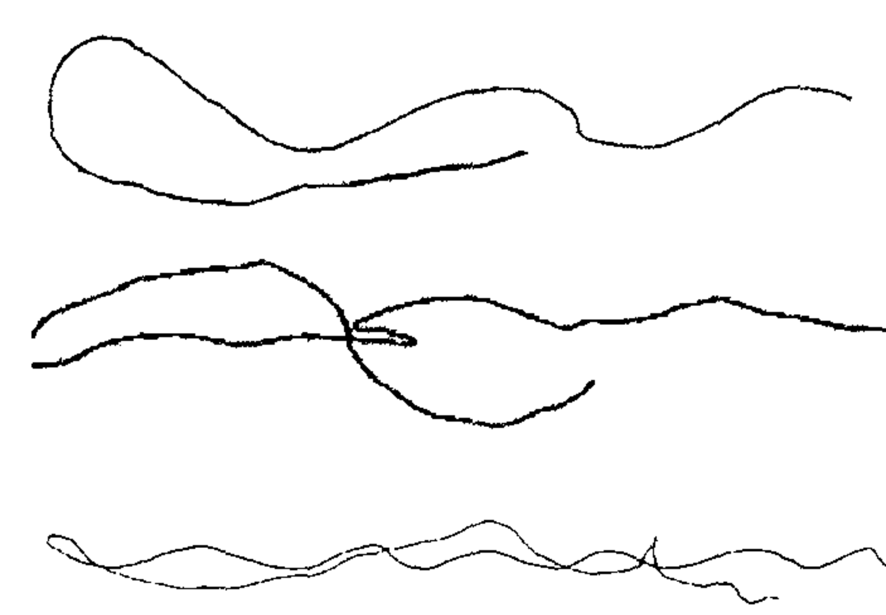
Analysis of the tracer fibre configuration is based on the assumption that the tracer fibres behaved typically like other cotton fibres. However, because of the dyeing process, it is likely that the frictional properties of the fibres change to a certain degree. Although the extent to which the fibre behaviour is affected by the spinning process is not known, it would be impossible to discount some differences in their behaviour during carding and drafting and this must be borne in mind in any tracer analysis.

The arrangement and the technique used for the fibre configuration study were discussed in detail in Chapter 2. The technique described is a method of studying the configuration of the individual fibres in the yarn, in order to yield positive information on fibre distortion.

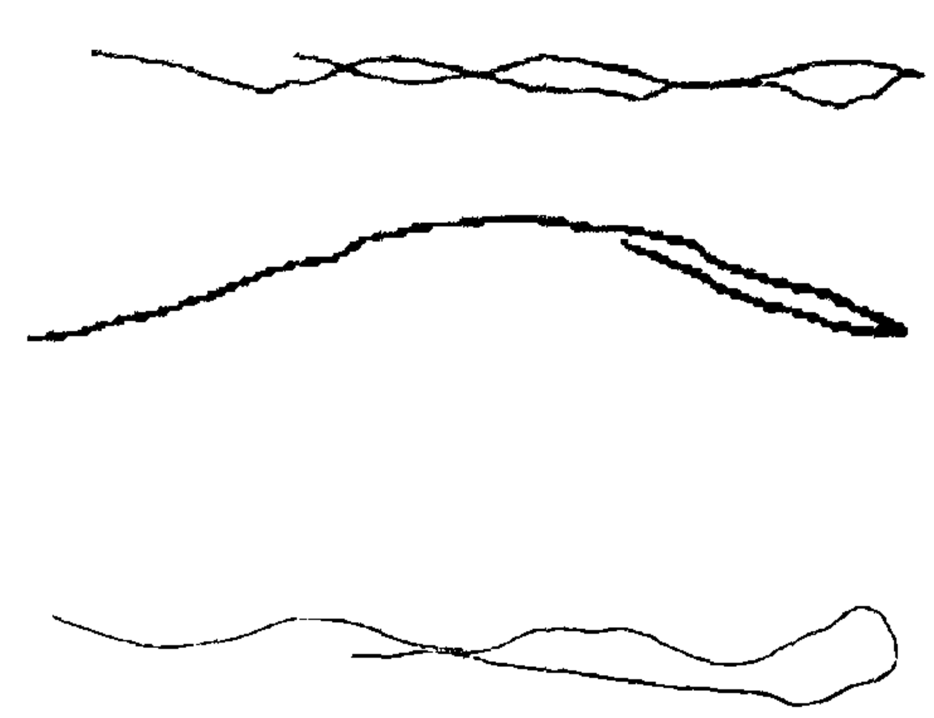
Figure 4.1 shows some of the fibre configurations observed during the analysis. Generally, the fibres can be classified into the following groups [64].

1. Fibres with trailing hooks
2. Fibres with leading hooks
3. Fibres that have both ends hooked
4. Fibres without hooks and
5. Fibres that do not come under any of the above categories (such as U-shaped fibres, fibre knots etc.).

Some Trailing Hooks observed



Some Leading Hooks observed



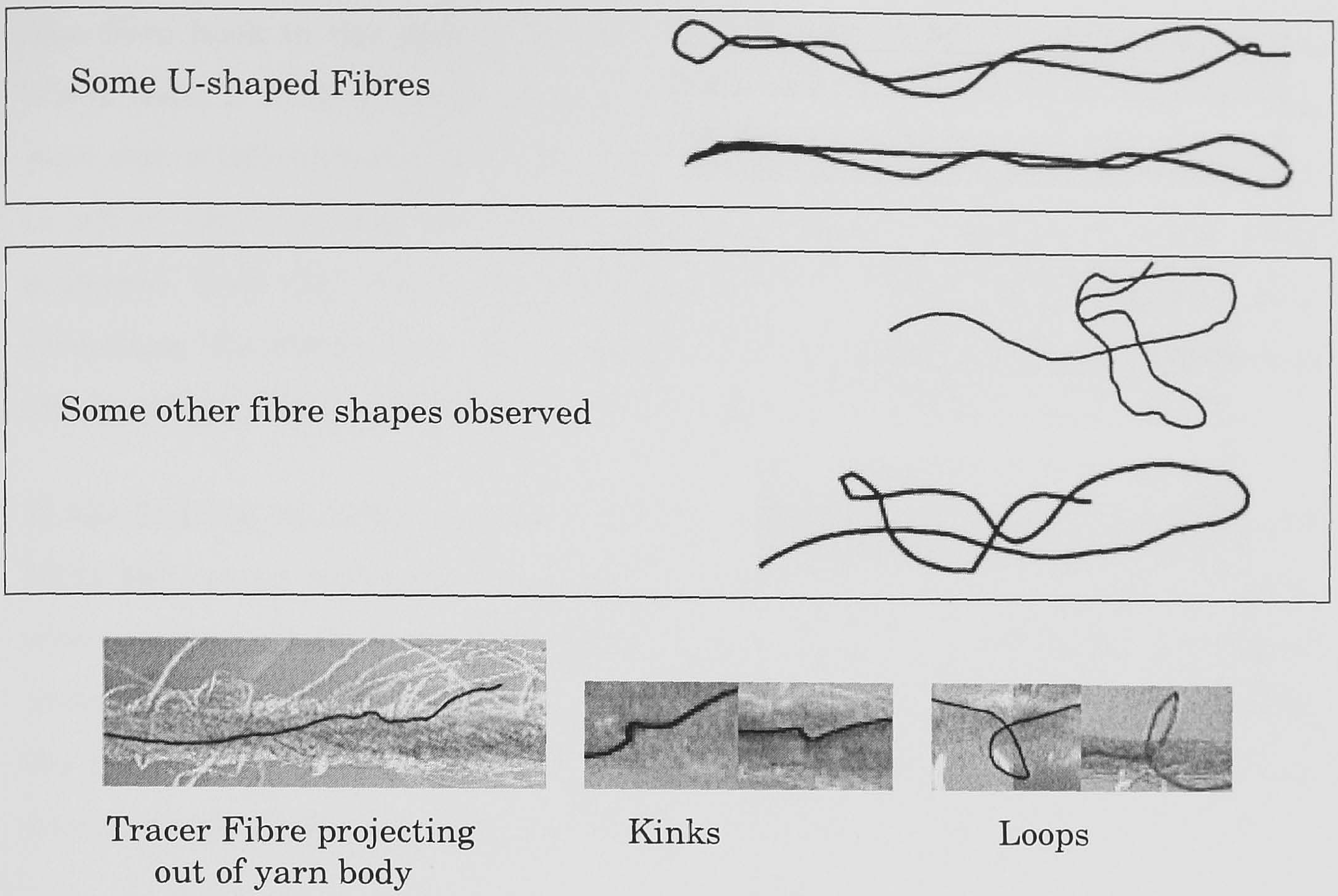
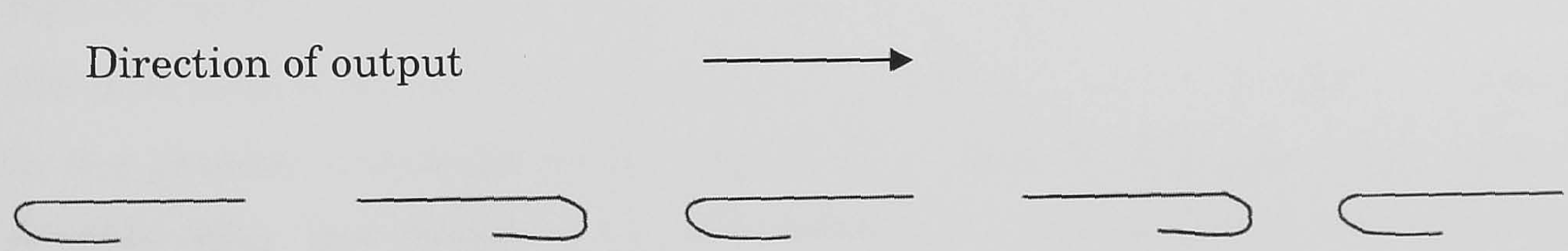


Figure 4.1: Some fibre Configurations in Yarn

4.2.3 Hooks in Card Sliver and Carded Ring Yarn

The hooks in a carding web undergo reversals during the intermediary processes before ring spinning. There are an odd number of processes between the carding and the ring-spinning machines in the manufacture of a carded ring yarn. A trailing hook in the card web ends up as a trailing hook when delivered from the front roller of the ring-spinning machine. Figure 4.2 shows the process of hook reversal for a trailing hook in the card web.



Card Web	**1st Draw-frame**	**2nd Draw-frame**	**Speed Frame**	**Spinning**
	Front roller	Front roller	Front roller	Front roller
Trailing	Leading	Trailing	Leading	Trailing

Figure 4.2- Hook reversal during the manufacture of carded yarn

The fibre hook in the yarn is in the same direction as the carding web (in the above case, a trailing hook) when the yarn is wound on the spinning cop. The yarn was withdrawn and observed under the microscope, by moving it from right to left so that the hook observed maintained the same direction as it was when delivered from the front roller nip (or as delivered in the carding machine). Therefore, the observations of the hooks in the ring yarn are directly correlated to the direction of hooks observed in the carding web.

In the findings of earlier workers like Nield and Ali [78], Ishtiaque *et al* [79] and Mills [46], yarns were found to contain more leading hooks than trailing hooks, whereas the yarn was expected to show more trailing hooks as the card sliver contains substantially more trailing hooks than leading hooks. It appears that the researchers might have measured the hook content in the yarn, as the yarn was unravelled from the package (possibly from left to right).

4.2.4 Kinks, loops and fibre twins in the yarn

The term 'kink' represents a fine crimp, fold or crease observed in the tracer fibre. Some kinks are very pronounced, while many are less pronounced. Observations in this work represent only those crimps that are pronounced. Examples of kinks and loops are shown in Figure 4.1.

'Loops', as the name implies are fibre coils that are produced either during the carding or during spinning processes.

Two fibres that appeared together have been referred to as 'Fibre twins'. The reasons for the existence of these twin fibres are unknown and it is possible that the card cannot achieve one hundred percent fibre-to-fibre separation. However, in the present investigation the 'fibre twins' were dyed tracer fibres and it is possible that the dyeing process itself could be responsible for some fibre stickiness.

4.2.5 Experimental Procedure

The yarn samples produced from the experiments are given in Table 4.1.

Table 4.1. Experiments and samples from single and triple licker-in systems:

PARAMETER	NHH 44 Cotton	DCH 32 Cotton	Number of Samples	
Single Licker-in				
	RPM	**RPM**	**NHH 44**	**DCH 32**
Single Licker-in Speeds (3 different speeds)	1440 1080 840	1080 840 590		
Production rate in kg per hour	30	10	**3**	**3**
Triple Licker-in				
Licker-in speeds: Roll 1 Roll 2 Roll 3	998 1568 2067	755 1202 1516		
Production rates in kg/ hr	30, 45, 60	10, 15, 20	**3**	**3**
GRAND TOTAL			**6**	**6**

From each of the six samples, 25 tracer fibre images were recorded for image analysis, making a total of 150 fibres taken from both the single licker-in and triple licker-in. These images were only used for fibre path analysis in the yarn including fibre extent.

A large number of fibres were observed for their fibre configuration within the yarn. One hundred tracer fibres from every sample were observed under the microscope for other aspects of fibre disposition, such as fibre hooks, loops, kinks etc. These observations did not include the measurement of fibre extent and hence these observations were recorded on paper for reference and analysis. Six hundred tracers for single licker-in and six hundred tracers for triple licker-in were observed in this manner.

4.3 Discussion of Results

4.3.1 Fibre Hooks, Kinks and other disorders

Table 4.2 gives the tracer results obtained for the Ne 20s yarn with both licker-in arrangements. It can be seen that trailing hooks are significantly greater in single licker-in yarn than in triple licker-in yarn. Even though there was no clear trend found with respect to hooks as far as the single licker-in was concerned, it should be noted that at the optimum licker-in speed of 840 rpm (from the yarn quality results), more hooks were produced than the triple licker-in (at the same production rate). The trailing hooks also appear to increase with an increase in production rate for the triple licker-in.

Table 4.2. Fibre configuration in yarns (Ne 20s)

Description	Triple Licker-in				Single Licker-in			
Production in kg/hr	**30**	**45**	**60**	**TOTAL**	**30**	**30**	**30**	**TOTAL**
Licker-in speed (rpm)	*	*	*		**1440**	**1080**	**840**	
Number of fibres	**100**	**100**	**100**	**300**	**100**	**100**	**100**	**300**
Trailing Hooks	7	8	9	**24**	12	9	14	**35**
Leading Hooks	5	3	11	**19**	5	2	7	**14**
Both Ends hooked	1	0	1	**2**	2	0	0	**2**
No hooks	86	87	78	**251**	78	86	75	**239**
Others: U-shaped	0	1	1	**2**	2	2	2	**6**
Other shapes	1	1	0	**2**	1	1	2	**4**
Fibre twins	8	7	9	**24**	4	4	5	**13**
Loop formation	1	1	3	**5**	2	2	3	**7**
Number of kinks	148	134	100	**382**	102	65	118	**285**
No. of fibre hairs projecting out of yarn body	47	51	51	**149**	39	46	36	**121**

* Licker-in speeds (rpm) from feed point (1st roll- 998, 2nd roll –1568 and 3rd roll – 2067)

As regards the other irregularities observed in the fibre paths, the triple licker-in exhibited a greater number of kinks as well as a greater number of fibre hair projections outside the yarn body. Surprisingly, with triple licker-in the number of kinks observed decreased as the production rate was increased, with the highest number of kinks (many of the kinks were very pronounced) observed at the lowest production rate. The triple licker-in also had a greater number of twinned fibres, while single licker-in had more fibres that were U-shaped (folded).

Table 4.3 shows the results obtained for the fine yarn (Ne 80s). It can be seen that number of trailing hooks in the fine yarn were found to be greater in number with the triple licker-in than with the single licker-in compared to the coarse yarn. Results also show that the single licker-in produced a greater number of leading hooks than the triple licker-in. At the optimum licker-in speed of 840 rpm (from the yarn quality results), the triple licker-in yarn had the greater number of trailing hooks while the single licker-in yarn had a greater number of leading hooks at the same production rate.

Table 4.3. Fibre Configuration in yarns (Ne 80s)

Description	**Triple Licker-in**				**Single Licker-in**			
Production in kg/hr	**10**	**15**	**20**	**TOTAL**	**10**	**10**	**10**	**TOTAL**
Licker-in speed (rpm)	**	**	**		**1080**	**840**	**590**	
Number of fibres	**100**	**100**	**100**	**300**	**100**	**100**	**100**	**300**
Trailing Hooks	24	22	21	**67**	18	17	19	**54**
Leading Hooks	2	1	4	**7**	6	5	4	**15**
Both Ends hooked	2	1	2	**5**	2	1	0	**3**
No hooks	70	75	70	**215**	71	72	76	**219**
Others: U-shaped	0	1	2	**3**	1	3	0	**4**
Other shapes	2	0	1	**3**	2	2	1	**5**
Fibre twins	4	4	5	**13**	1	4	4	**9**
Loop formation	8	3	6	**17**	7	9	5	**21**
Number of kinks	64	65	38	**167**	56	77	30	**163**
No. of fibre hairs projecting out of yarn body	67	80	74	**221**	65	71	73	**209**

** Licker-in speeds from feed point (1st -755, 2nd –1202 and 3rd – 1516)

Other irregularities observed in the fibre paths were found to be greater in the finer yarns than in the coarse yarns, especially loops and fibre hairs projecting out of the yarn body. Though a definite trend was not observed with reference to kinks, they were in general lower in number in the finer yarn. The lowest number of kinks was observed at the highest production rate (as with the coarser yarn) with the triple licker-in, as well as at the lowest licker-in speed with the single licker-in. For the finer yarn, it also appears that a decrease in licker-in speed with single licker-in seems to slightly increase the number of fibres projecting out of the yarn body. Also at the highest speed, the single licker-in showed the least number of fibre twins.

4.3.2 Fibre Extent Ratio

From each of the six samples, 25 tracer fibre images were recorded for analysis, making a total of 150 fibres from the single licker-in and triple licker-in respectively. The tracer fibres were traced using Paintshop and extracted using Photoshop. The procedure is explained in detail in Chapter 2, Section 2.9.1. The tracer fibre configurations in the yarn for single and triple licker-in systems are shown in Appendices 19-30.

It is relatively easy to discern differences in fibre configurations in the fine yarn (Ne 80s). Yarns produced with a single licker-in at 590 rpm and 840 rpm show much more perceptible order than yarns produced with a licker-in speed of 1080 rpm or with the triple licker-in. However, finding the differences among the coarser yarns (Ne 20s) was difficult. The differences are so subtle that they could not be discerned with a naked eye and could only be discerned under high magnification (under a microscope) or by analysing the fibre paths in the yarn using advanced image analysis software. Some interesting results were noticed when the fibre path was analysed using 'Image Pro Plus' software. For the fibre path analysis within the yarn, a new expression has been derived and termed as 'Fibre Extent Ratio' and it will be referred to as FER hereafter. The FER is defined by the following formula.

$$\text{Fibre Extent Ratio (FER) \%} = \frac{(\text{Fibre Length} - \text{Fibre Extent}) \times 100}{\text{Fibre Length}}$$

Please note that the above expression is similar to 'Crimp Ratio' and it has been rephrased to 'Fibre Extent Ratio' to distinguish it from the measurement of crimp. It should be noted that only the unhooked fibre length was taken into account for the FER calculation as shown in Figure 4.3. This way the gross variations brought about by the differences in hook numbers was eliminated and only subtle variations are highlighted.

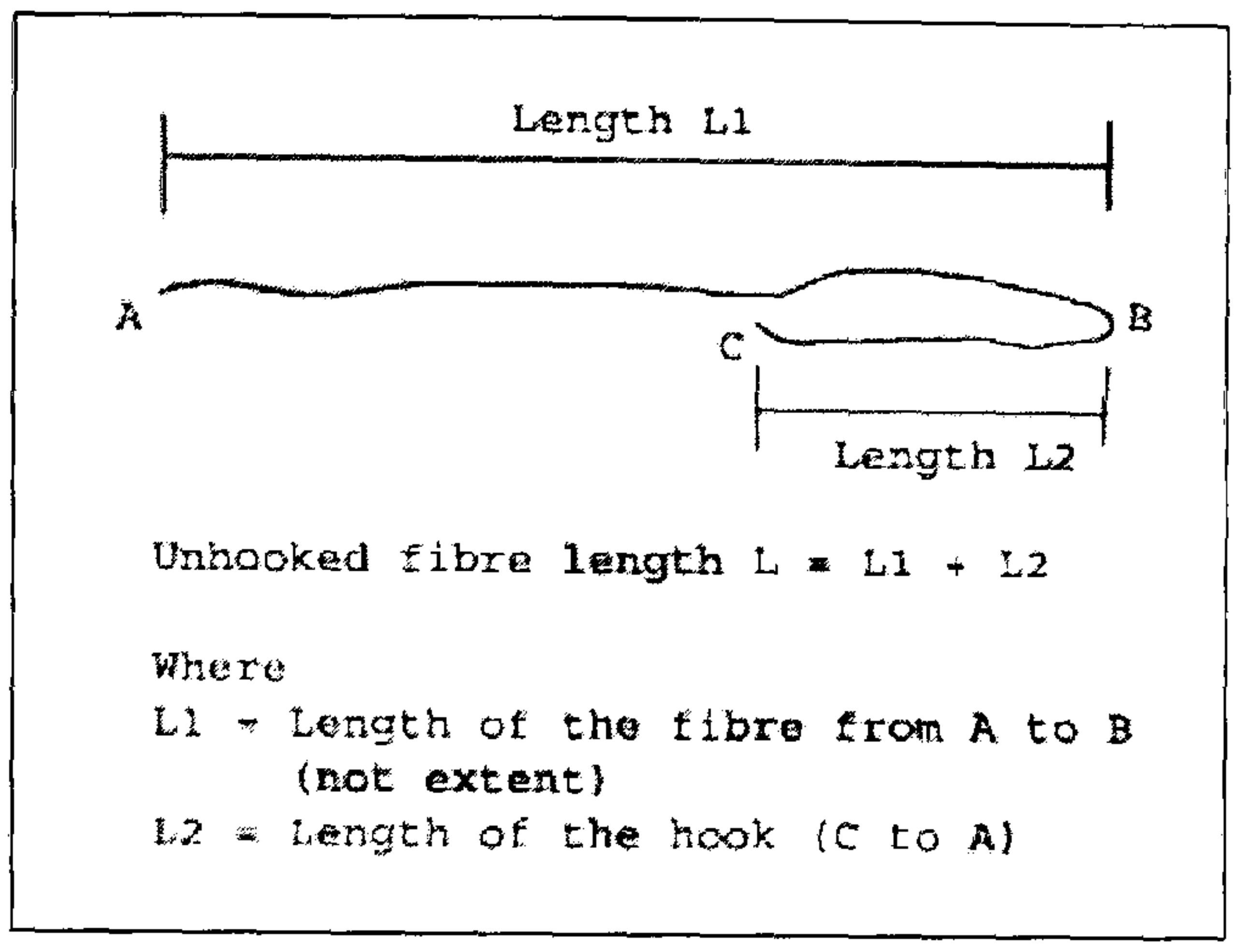


Figure 4.4 – Unhooked length

The calculations are based on weighted average and not the number average, so a more meaningful representation can be achieved i.e. longer fibres contributing more to the mean FER than shorter ones. An example has been shown in Table 4.4.

Table 4.4– Calculation of FER

Fibre No	Fibre Length (mm)	Fibre Extent (mm)	FER %
1	15.5	14.3	7.7
2	17.8	16.5	7.3
3	13.6	12.1	11.0
4	26.1	25.4	2.7
5	30.4	29.1	4.3
	Mean FL = 20.68	Mean FE = 19.48	Mean FER = 6.6 %

As per the method of calculation used in this investigation it will be,

$$FER = \frac{(\text{Mean FL} - \text{Mean FE}) \times 100}{\text{Mean FL}}$$

$$FER = \frac{(20.68 - 19.48) \times 100}{20.68} = 5.8\%$$

The weighted FER value is only 5.8% as against mean of FER values which was 6.6% because in this case the longer fibres contributed more to the FER than the shorter ones.

It was observed that fibre extent ratio (FER) was greatest for short fibres and it decreased as fibre length increased. Hence, it was thought that it would make better sense if fibres were also grouped according to the fibre extent and the weighted average FER of each group. Three such groups of fibres represent every sample.

Group 1 - Fibre extent less than 15 mm.
Group 2 - Fibre extent between 15 mm and 25 mm.
Group 3 – Fibre extent greater than 25 mm.

The FER values for each length group obtained with single and triple licker-in systems are given in the Appendix 17.

4.3.2.1 Fibre Extent Ratio vs. Fibre Length

Figures 4.4 and 4.5 show the FER with single licker-in and triple licker-in for the Ne 20s yarn and figures 4.6 and 4.7 represent the single and triple licker-in results of Ne 80s yarn. It is seen that in general the FER decreases as the fibre length increases. It is also seen that the highest licker-in speed shows greater value of FER for all fibre length groups for both yarn counts.

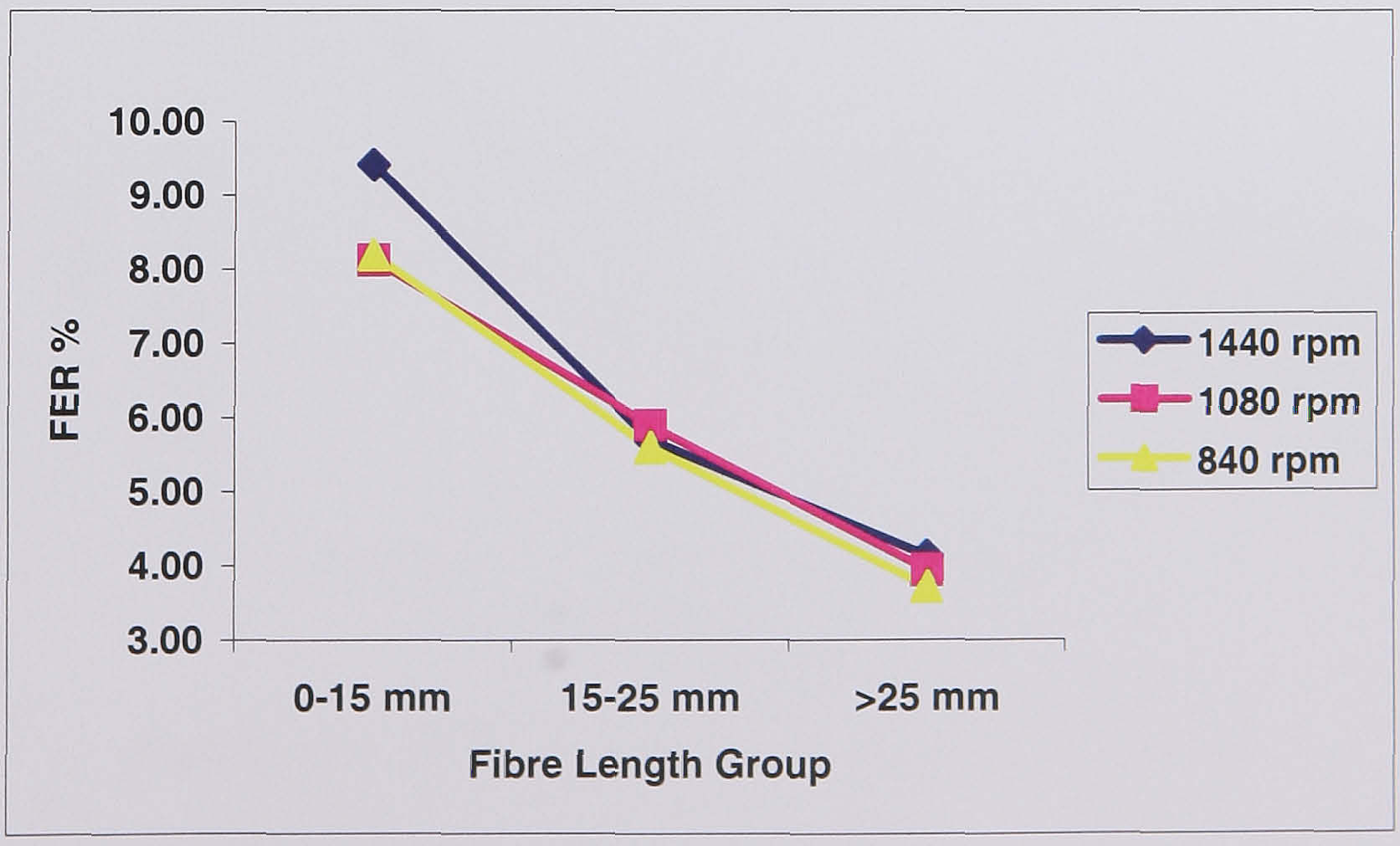


Figure 4.4 – FER with single licker-in for Ne 20s yarn

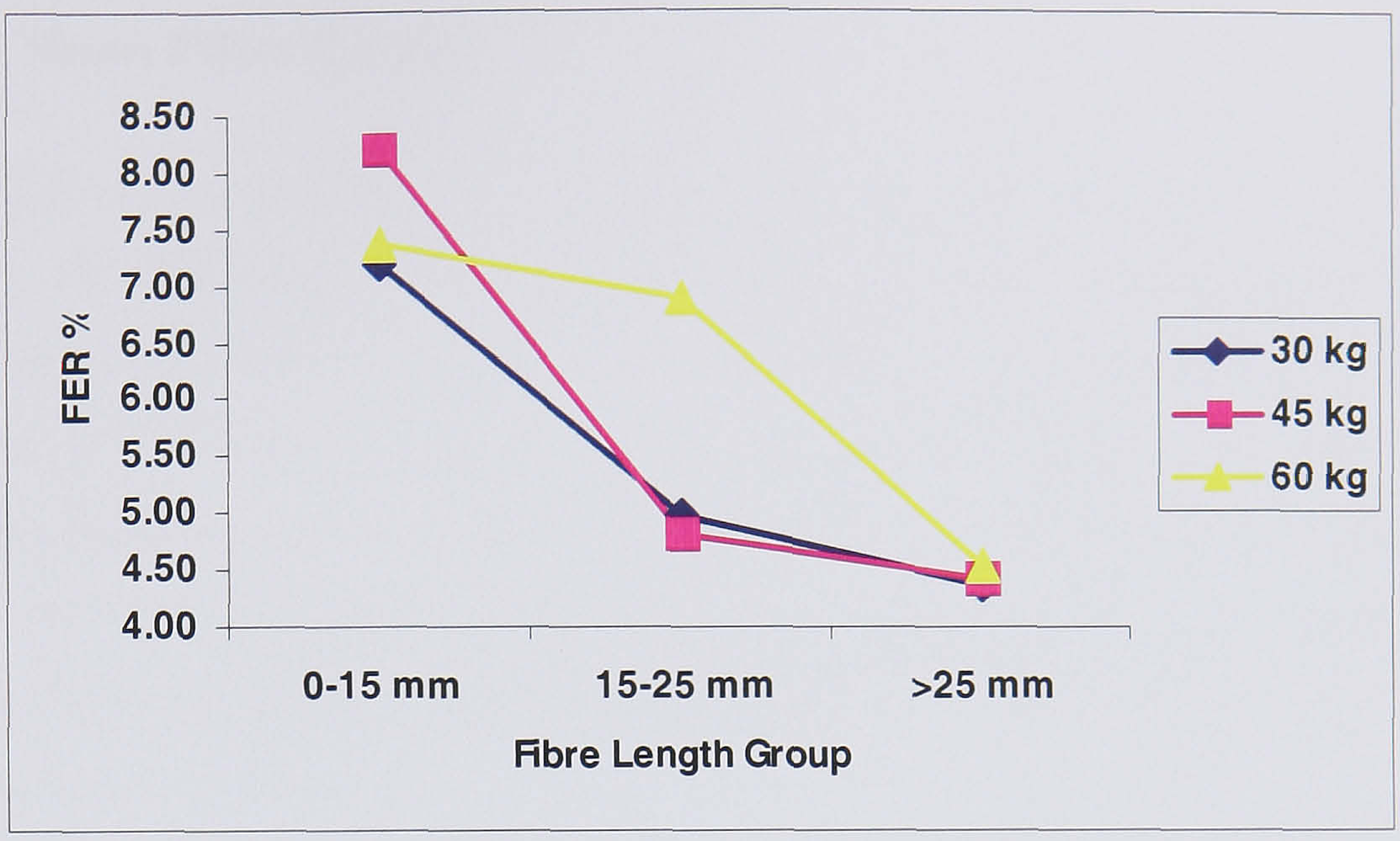


Figure 4.5 – FER with triple licker-in for Ne 20s yarn

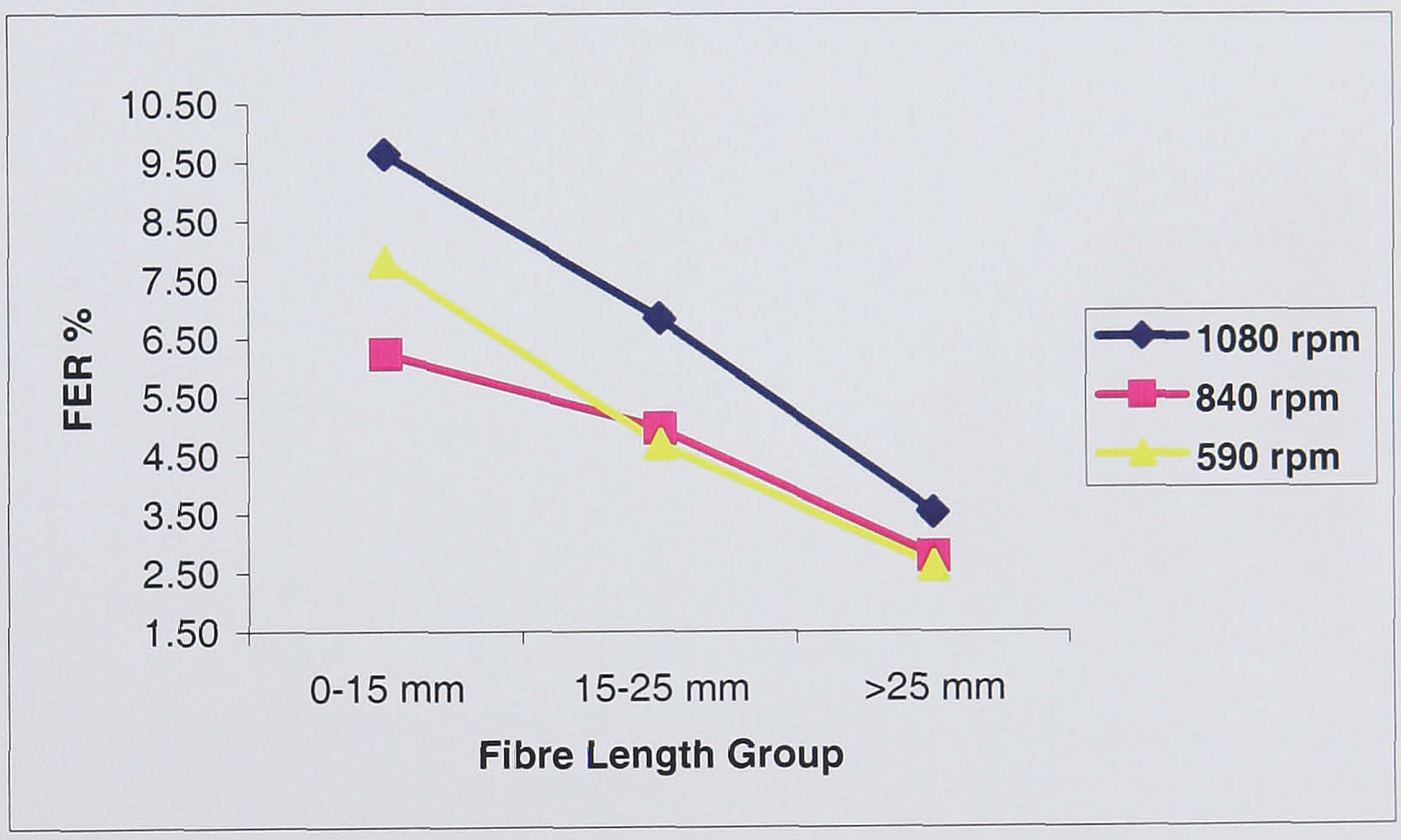


Figure 4.6 – FER with single licker-in for Ne 80s yarn

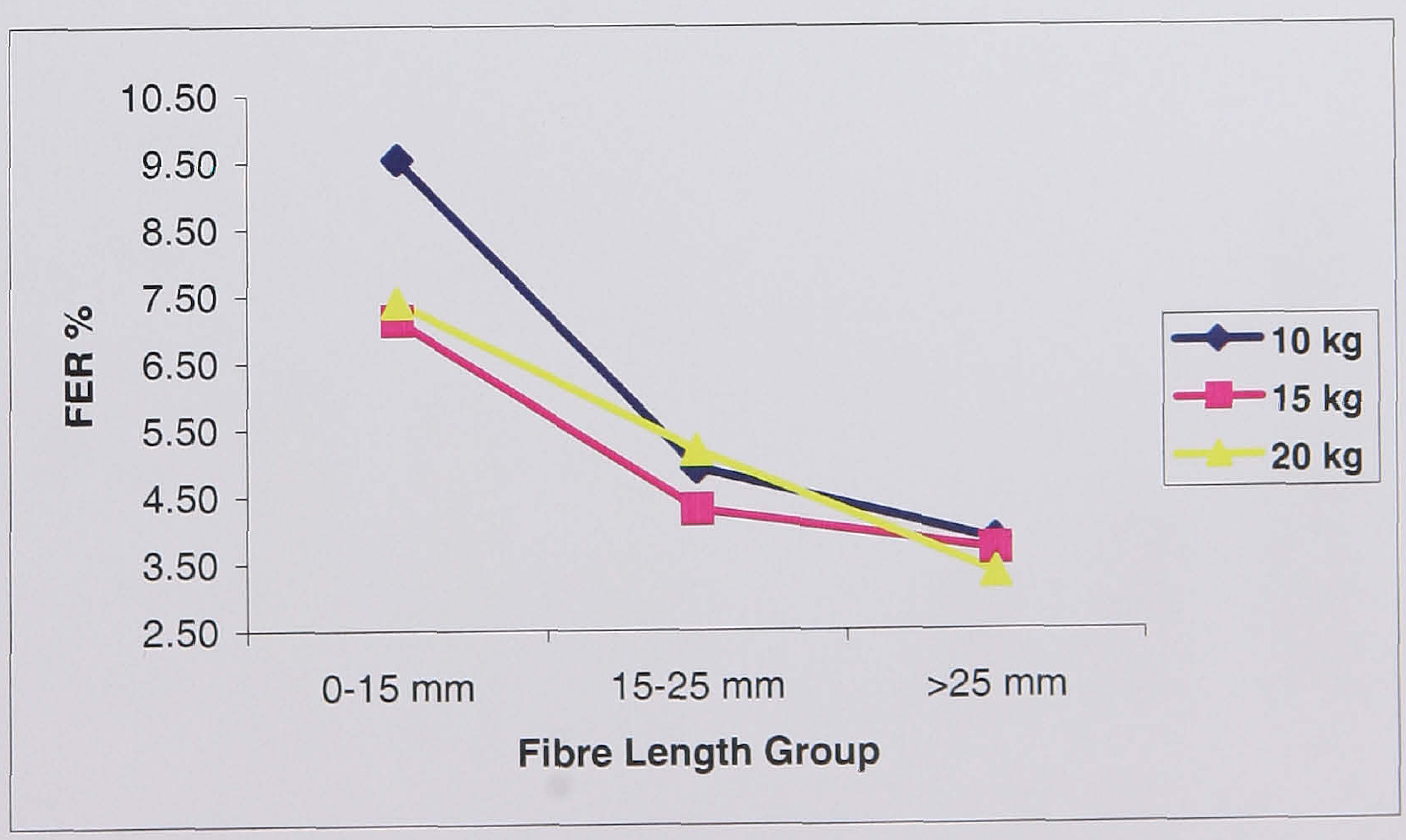


Figure 4.7 – FER with triple licker-in for Ne 80s yarn

4.3.2.2 Mean Fibre Extent

Mean FER values are shown in Figure 4.8 for Ne 20s. We see that for the triple licker-in, the FER value increases with an increase in production rate and is significantly higher at 60-kg/hr. In the case of the single licker-in, the mean FER increases with licker-in speed. The increase is higher when the speed is increased from 840 to 1080 rpm initially and after that, only a small increase is noticed. At the optimum licker-in speed of 840 rpm (obtained from the yarn results), the mean FER is slightly higher than that of triple licker-in yarns at a production rate of 30-kg/hr.

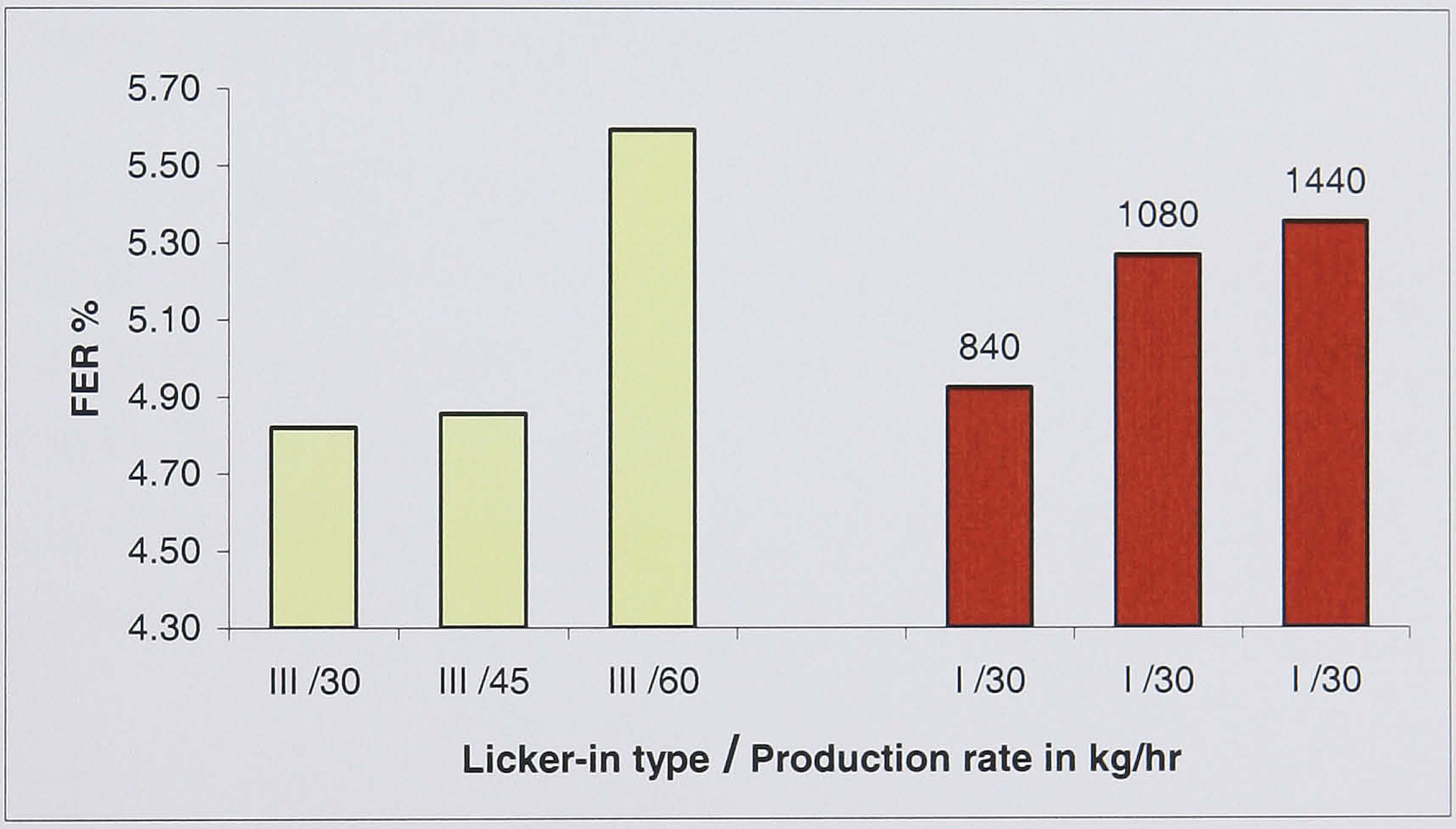


Figure 4.8 – Mean FER in Ne 20s yarn

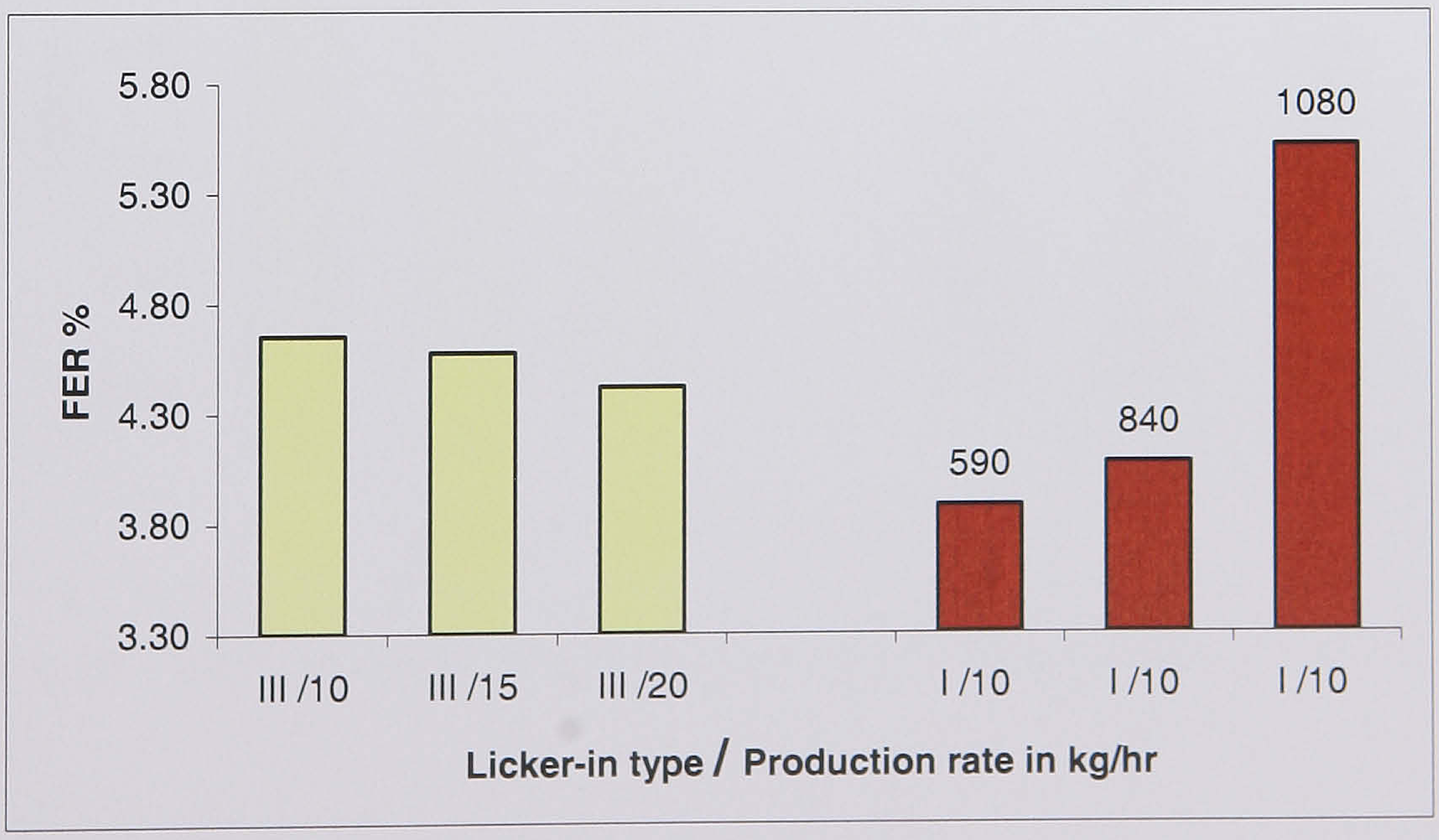


Figure 4.9 – Mean FER in Ne 80s yarn

Mean values of FER are shown in Figure 4.9 for Ne 80s yarn. In the case of the finer yarn (Ne 80s), it is seen that there is only a small change in FER (< 5%) as the production rate is increased with triple licker-in (unlike the coarser yarn). However, triple licker-in shows a higher value of FER than the single licker-in (at the optimum single licker-in speed of 840 rpm from quality results) at the same production rate of 10-kg/ hr. Finer yarn, like coarser yarn, shows an increase in FER with an increase in single licker-in speed, with the highest speed recording a significant increase. It can be seen the FER values increase when the licker-in speeds are increased from 840 rpm and 1080 rpm for both Ne 20 and Ne 80 yarns.

4.3.2.3 FER values for fibres longer than 25 mm

It is seen from Figures 4.4 – 4.7 that the mean FER changes are mainly influenced by the FER value of the longer group of fibres because of the weighted average measurement of FER. It was also observed that the FER values of the longer length group of fibres (>25 mm) were more influenced by the licker-in design and single licker-in speed. Figure 4.10 and 4.11 show the FER values of the longer length group of fibres for Ne 20s and Ne 80s yarns respectively.

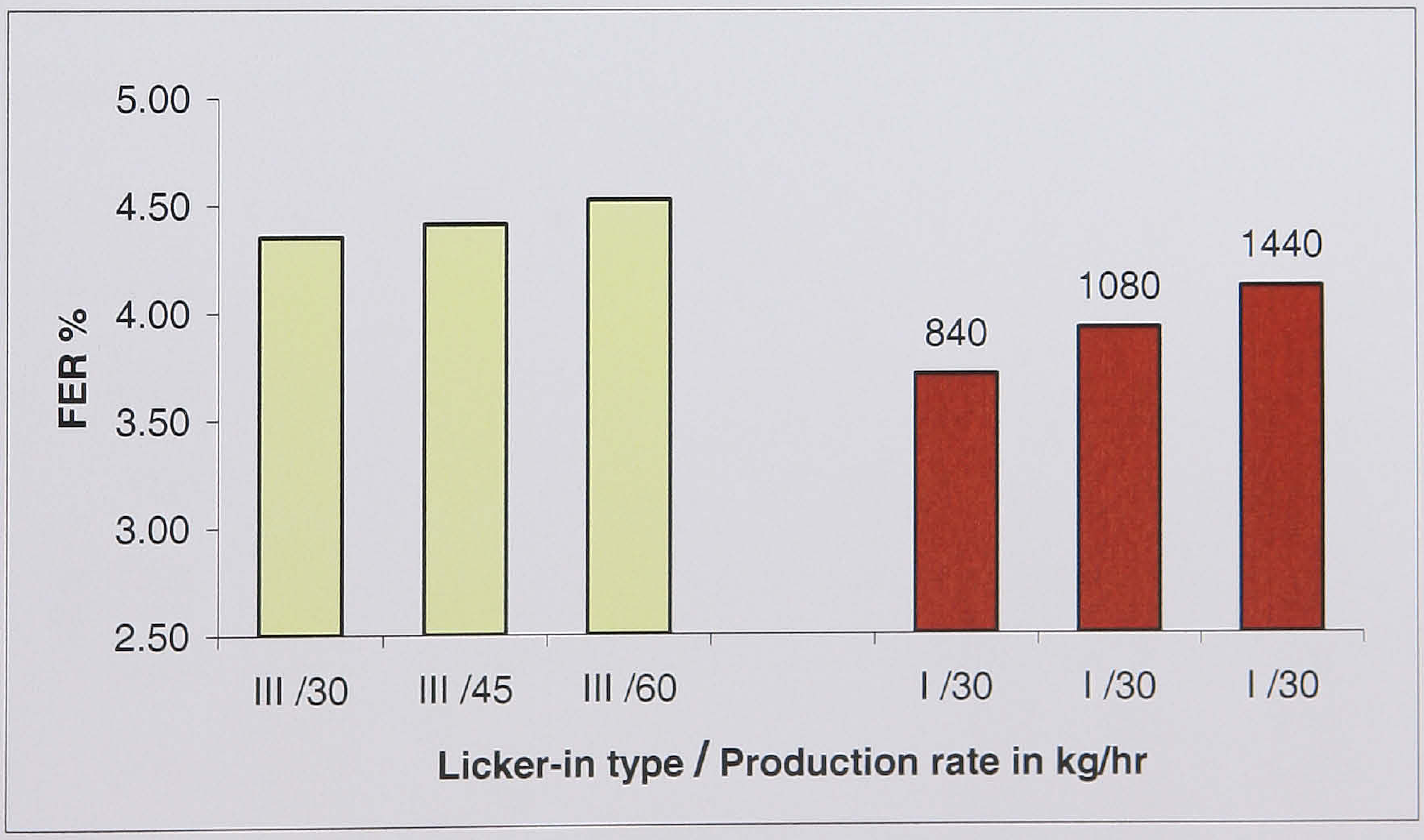


Figure 4.10 – FER for fibres with an extent greater than 25 mm in Ne 20s yarn

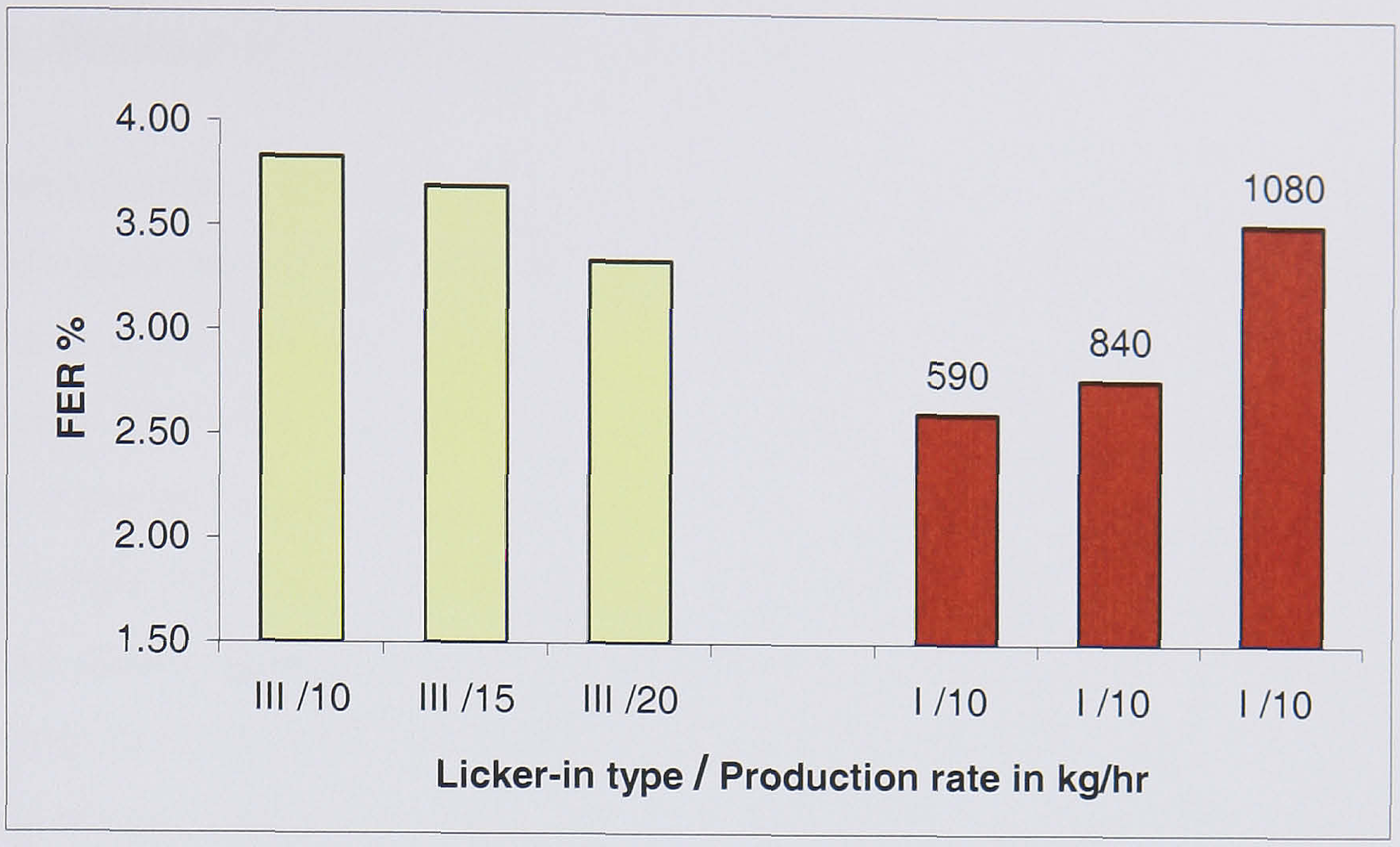


Figure 4.11 –FER for fibres with an extent greater than 25 mm in Ne 80s yarn

It is evident from figures 4.10 and 4.11 that the longer tracer fibres in triple licker-in yarns have greater FER than those in the single licker-in yarns. In both cases, the licker-in design and licker-in speed seem to mainly influence the longer fibres (>25mm) of the coarser cotton. In the case of finer cotton, even fibres longer than 15 mm (figure 4.12) are influenced by the single licker-in speed. At the highest speed of 1080 rpm for the finer DCH cotton (Ne 80s), the FER values are significantly greater than at the other speeds. In general, the fibres in the finer yarn show a smaller value of FER and this could possibly be due to either the greater amount of draft involved in spinning them or the fibre characteristics.

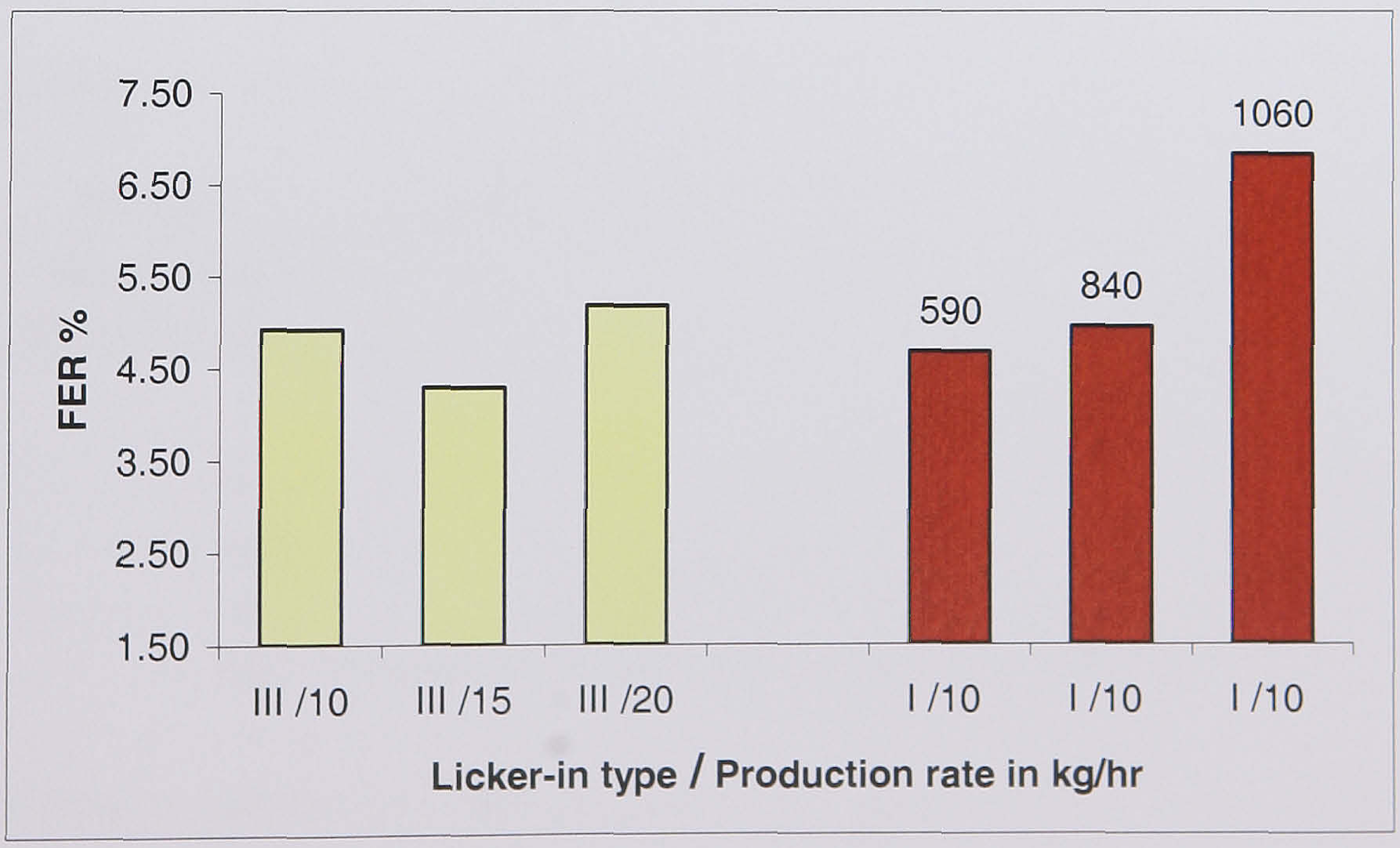


Figure 4.12 –FER for fibres with an extent of 15 to 25 mm in Ne 80s yarn

4.3.2.4 Statistical significance of the findings

The main feature of the experimental work was to observe the trends when the licker-in or production parameters are varied. Hence, if there were noticeable and consistent trends in the results, it could be safely assumed that the results are significant. However, in addition, 't' tests were carried out to establish whether the results are statistically significant at 95% confidence levels. Because of the small sample size used (25 fibres) for fibre extent studies, it was rather difficult to expect clear significance statistically. The FER values for fibres longer than 25 mm were compared as they contribute significantly to the mean FER values because of the weighted average measurement. However, Tables 4.5 and 4.6 show that there is statistical significance in the findings. The triple licker-in at the same production rate as the single licker-in was used as the reference (indicated as 'R') for comparison with all other single and triple licker-in experiments.

Table 4.5: Significance of results for FER for fibres > 25mm for Ne 20s Yarn

Licker-in type	**Triple Licker-in**			**Single Licker-in**		
Sample	**30 kg/hr**	**45 kg/hr**	**60 kg/hr**	**1440 rpm**	**1080 rpm**	**840 rpm**
Statistical Significance	**R**	**CS**	**CS**	**S**	**S**	**S**

Table 4.6: Significance of results for FER for fibres > 25mm for Ne 80s Yarn

Licker-in type	**Triple Licker-in**			**Single Licker-in**		
Sample	**10 kg/hr**	**15 kg/hr**	**20 kg/hr**	**1080 rpm**	**840 rpm**	**590 rpm**
Statistical Significance	**R**	**NS**	**NS**	**NS**	**CS**	**S**

R	**Reference case**
NS	**Not significant**
S	**Significant**
CS	**Closer to 95% significant levels**

Some of the 't' values were fairly high and it is possible that these results would have been significant if larger sample sizes were used. They are indicated as 'CS' in the above tables.

4.4 Summary and Conclusions

It is apparent from the results that with both fine and coarse cottons, fibre hooks, disorders like kinks, loops and fibre projections outside the yarn body are influenced to varying degrees by the licker-in arrangement. While analysing the results, it should be borne in mind that the fibre configurations were analysed at the yarn stage and not in the card sliver, where the disorder is greater, as every drafting passage reduces the disorder or leads to some change in the fibre configuration. While the hooks seem to be influenced by the licker-in design, there is some evidence to indicate that when the triple licker-in is used, the carding rate also has an influence over the number of trailing hooks.

Even though the use of tracer fibre image analysis to measure fibre configuration in the yarn is time consuming, in addition to the measurement of fibre extent and fibre hooks, it can also be used to bring out another aspect of fibre configuration that is, fibre path analysis within the yarn. The changes in fibre configuration are only visible under high magnifications and to quantify them, it is necessary to use a more sophisticated image analysis technique. By using the latest image analysis software, it was possible to establish differences in the fibre paths within the yarn.

With both types of cotton and with both licker-in systems, it is clear that the FER, especially that of the longer length group of fibres is influenced by the licker-in arrangement and the licker-in speed. The difference in the values of the FER between the single and triple licker-in designs seems to suggest that the fibres have a certain variation in the values of crimp, in other words two fibres that have the same fibre length have differing crimp resulting in different fibre extents.

In a single licker-in system, the FER reduction with reduction of licker-in speed could be attributed to two things: firstly, this could be attributed to the increase in surface speed ratio between the licker-in and cylinder. In these studies, the surface speed ratios exceeded 1:3 at the lowest licker-in speeds used. At a given cylinder speed, at the fibre transfer point between licker-in and cylinder lowering licker-in speed increases the amount of draft (combing) by the cylinder. Fujino [42] and Dehghani [40] found that there is a certain degree of improvement in fibre alignment on the cylinder immediately after the fibres are transferred from the licker-in, when compared to the alignment on the licker-in. An improved fibre orientation on the cylinder (before the revolving flats) may actually help in improving the carding action between the cylinder and the flats, resulting in a better orientation of the fibres transferred to the doffer.

The second reason could be that at higher licker-in speeds, the fibres may lose their orientation and become more disordered due to high centrifugal forces and a lack of control over the fibres by the licker-in clothing. Fujino [42] found that the orientation of fibres on the cylinder decreased with an increase in licker-in speed (licker-in/cylinder speed ratios from 1:2.55 to 1:1.1). It is not hard to recognize that the licker-in may not exert as much control over the fibres as the cylinder is able to, due to the low clothing population. The two afore mentioned factors may together be contributing to greater fibre disorder at higher licker-in speeds.

As far as the triple licker-in is concerned, an increase in the fibre disorder observed such as kinks (in the case of coarser cotton), or greater FER (in the case of longer fibres) etc., could be attributed to the following.

- Since the speed of the first licker-in is significantly lower at high carding rates, the degree of combing at the first licker-in is also significantly reduced.

- In spite of using greater clothing population, the lickers-in (second and third) may not exercise adequate control over the fibres due firstly to the high centrifugal forces brought about by the smaller diameter of the lickers-in (175 mm) and secondly, to the greater number of contact surfaces. Depending on fibre characteristics, this may lead to greater fibre disorder.

It has been established in this study that the licker-in design, speed and carding rates have an impact on the degree of fibre disorder in the yarn in spite of the number of intermediate drafting passages. It was also established that the longer fibres are more influenced by the licker-in parameter/design than short fibres.

It has thus been established that the fibre dynamics in the licker-in zone influence the fibre configuration in yarns and also the fibre, yarn and fabric quality results, when the licker-in parameters /design are changed. An investigation was therefore carried out to study the fibre disposition on the licker-in surfaces in order to understand fibre dynamics in the licker-in zone, using high-speed video photography. In the next chapter, the results of investigations using high-speed photography are presented.

Chapter 5

Phase III Experimentation: Study of fibre flow on the Licker-in Surfaces using High-speed Photography

5.1 Introduction

Chapters 3 and 4 respectively dealt with carding performance in terms of quality and fibre configuration in yarns produced with the single and triple licker-in designs used on modern carding machines. It was established in the studies that the pre-opening process in the licker-in zone makes a significant contribution to the carding performance. Chapter 5 is an attempt to enhance the understanding of what happens in the licker-in zone of the two licker-in designs using high-speed video photography.

With the advent of laser high-speed photography, it is possible to look at objects moving at very high speeds, for example a bullet speeding out of a gun. In the University of Leeds, laser high-speed photography was successfully carried out to study the fibre / tuft disposition on licker-in, cylinder and doffer of a high-speed carding machine [40]. In this work, fibres and tufts, as they passed through the licker-in surface/s of single and triple licker-in arrangements at high speeds, were observed for changes in fibre dispositions that may influence the carding performance and fibre configurations in card sliver and yarn.

5.2 Methodology

The same cotton varieties used during Phase I experimentation (quality trials) were used in this study. The fibre parameters of the two cotton varieties used in this study are given in Table 5.1.

Table 5.1: HVI and AFIS fibre test results

	NHH 44	DCH 32
HVI Results		
2.5 % Span length	27.61 mm	33.53 mm
50 % Span length	12.77 mm	14.45 mm
Uniformity ratio	46.3 %	43.1 %
Fibre strength in gms/ tex	20.04	26.39
Fibre elongation	5.8 %	6.2 %
Fibre micronaire value	4.2	3.0
AFIS Results		
Upper Quartile Length UQL (W)	28.2	35.4
Short fibre content (W) %	10.4	11.5
Fineness (millitex)	162	129
Maturity ratio %	0.9	0.79
Immature fibre content %	6.3	11.6
Neps per gram	100	498

5.2.1 Blow Room

Before being despatched to the University of Leeds, the cottons were processed through the blow-room process in the Indian spinning mill for preliminary opening and cleaning. This was required primarily because the blow-room at the University's laboratory did not have any cleaning machine and could only be used to produce laps from a given raw material with minimum opening. The sequence used for cleaning the cotton in the Indian spinning mill was as follows.

Mixing ⟶ Rieter Uniclean ⟶ Lakshmi Rieter ERM cleaner

The sequence of machines used for the preparation of laps in the University's Blow-room line was as follows.

Truetzschler mixing bale opener ⟶ Truetzschler scutcher

Laps were produced with the following linear densities.

NHH 44 – 450 gms/metre

DCH 32 – 400 gms/metre

It should be noted that the linear densities used in the laboratory experiments were about 10% heavier than those used in the spinning mill. In spite of several attempts, the lap weight could not be brought down to the lap weights used during Phase I experimentation, 420 grams for the medium NHH 44 cotton and 350 grams for the long DCH 32 cotton.

5.2.2 Carding

The University's carding laboratory had a Crosrol Mark IV high-production card that was used for the single licker-in experiments. The construction of the single licker-in in Mark IV card is similar to Mark V card, which is shown in Figure 3.1, chapter 3.

This single licker-in arrangement used in the Crosrol Mark IV card was similar to the arrangement in Crosrol Mark V card used for the fibre and yarn quality trials in the Indian spinning mill. The settings of the licker-in region were changed to the settings that were used for the quality trials (Phase I experimentation), which are given in Table 3.3.

Roller dimensions and the clothing specifications used on individual rollers of the Mark IV card are given in Table 5.2.

Table 5.2 – Roller specifications of the Crosrol MK IV carding machine

Roller	Diameter (mm)	Wire Population (ppsi)
Feed roller	100	-
Licker-in	254	42
Cylinder	1016	860
Doffer	508	378

The condition of the card clothing in terms of sharpness of all carding rollers was good on the carding machine. The card also had a continuous flats waste evacuation system.

The triple licker-in unit that was used for the quality trials in India (Phase I experimentation) was shipped to the University of Leeds for trials using high-speed photography. It was initially proposed to fit this triple licker-in system to the laboratory-carding machine however, due to the practical difficulties in fitting the unit to the laboratory carding machine, it was decided to install the triple licker-in system as a stand-alone system. The arrangement of the triple licker-in as a standalone unit was discussed in detail in Chapter 2, Section 2.7.2.

The specifications of card clothing used on the individual rollers of the triple licker-in unit are given in Chapter 3 (Table 3.4). The settings used in the licker-in zone of the triple licker-in arrangement are given in Table 3.5 of Chapter 3.

Table 5.3 gives the details of the process used with the single and triple licker-in arrangements. It should be noted that the actual roll speeds measured for the triple licker-in were found to be slightly higher than the speeds used in Phase I experimentation, by about 3 to 4%. This difference may have been due to belt tension.

Table 5.3: Licker-in speeds and production rates with single and triple licker-in systems

PARAMETER	NHH 44 Cotton		DCH 32 Cotton	
Single licker-in				
	RPM	m/s	RPM	m/s
Single Licker-in Speeds (3 different speeds)	1440 1080 840	19.15 14.36 11.17	1080 840 590	14.10 11.17 7.84
Cylinder speed	640	34.06	500	26.61
Production rate in kg /hour	(10, 20), **30**		**10**, (15, 20)	
Triple licker-in				
Licker-in speeds: Roll 1 Roll 2 Roll 3	 1024 1632 2068	 9.22 14.70 18.62	 785 1252 1584	 7.07 11.27 14.26
Production rates in kg/ hr	(10), **30**, 45, 60		**10**, 15, 20	

As is evident from Table 5.3, the same process parameters used for quality trials were used during this phase of experimentation. In addition, a few more production rates (shown within brackets) were added to this phase of the investigation, to study the effect of production rates on the opening process especially with the single licker-in arrangement. The main or core conditions, which gave the best quality results from the single and triple licker-in trials are highlighted in Table 5.4 (page 171).

5.2.3 Image Analysis of the captured images from high-speed photography

For high-speed photography, suitable observation windows in the licker-in region were created in such a way that the fibre flow through the carding machine was not disturbed (arrangement explained in detail in Chapter 2, Section 2.8.4). The methodology adopted for image processing and analysis is discussed in Chapter 2, Section 2.9.2. Figure 5.1 shows the position of the observation window used to photograph the single licker-in and Figure 5.2 shows the positions of windows in the triple licker-in unit.

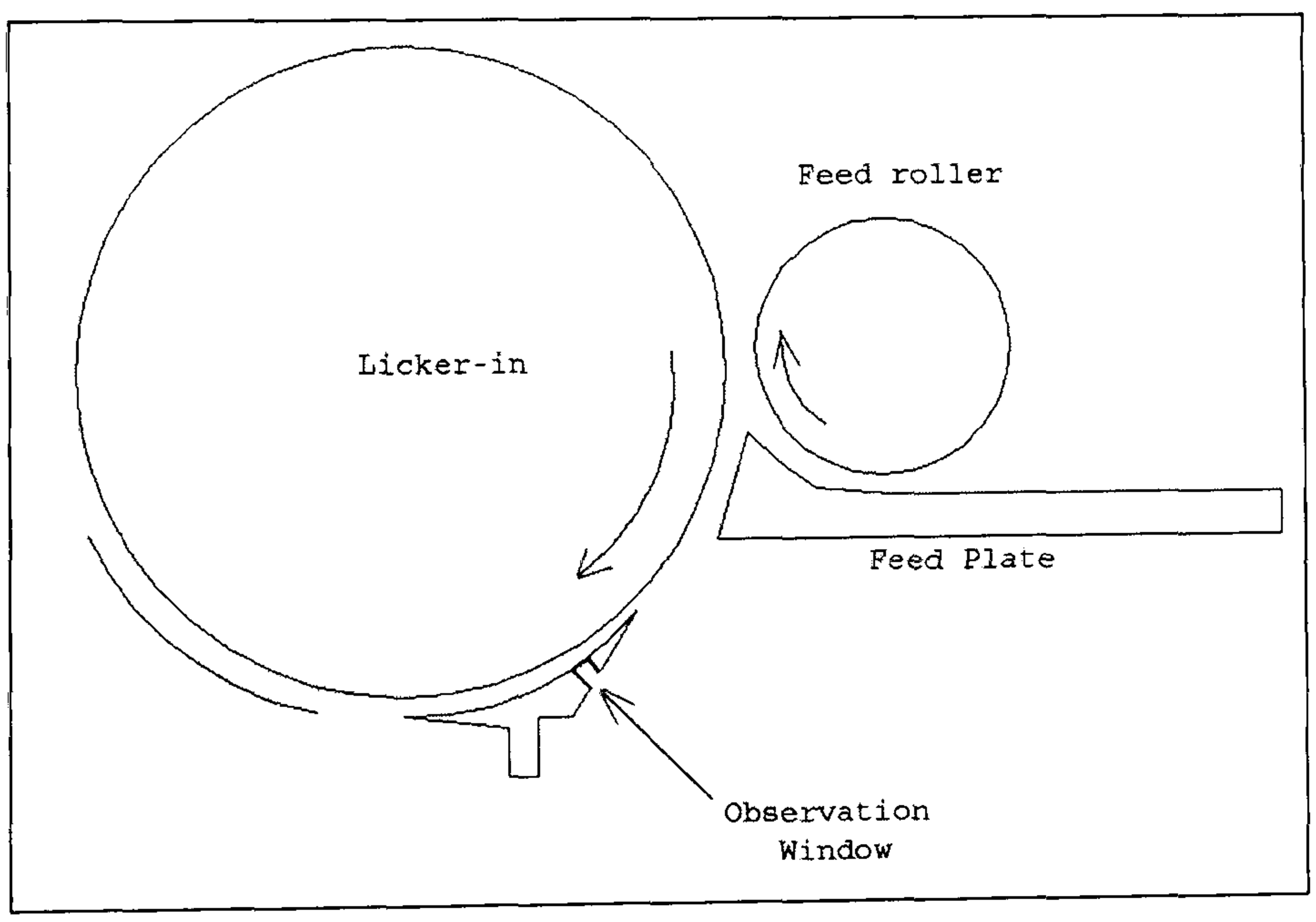


Figure 5.1 – Position of window in Single Licker-in

One of the main objectives of using high-speed photography in this study was to observe the fibre disposition on the licker-in before the fibres were transferred to the main carding cylinder. Therefore, the images of fibre flow captured on the single licker-in and on third roller of the triple licker-in (observation window number 4) were analysed using image analysis software. Photography was also carried out on the first roller of the triple licker-in (through window 2) to study the fibre opening process and on the first and second rollers (through windows 1 and 3) to detect any evidence of fibre recycling.

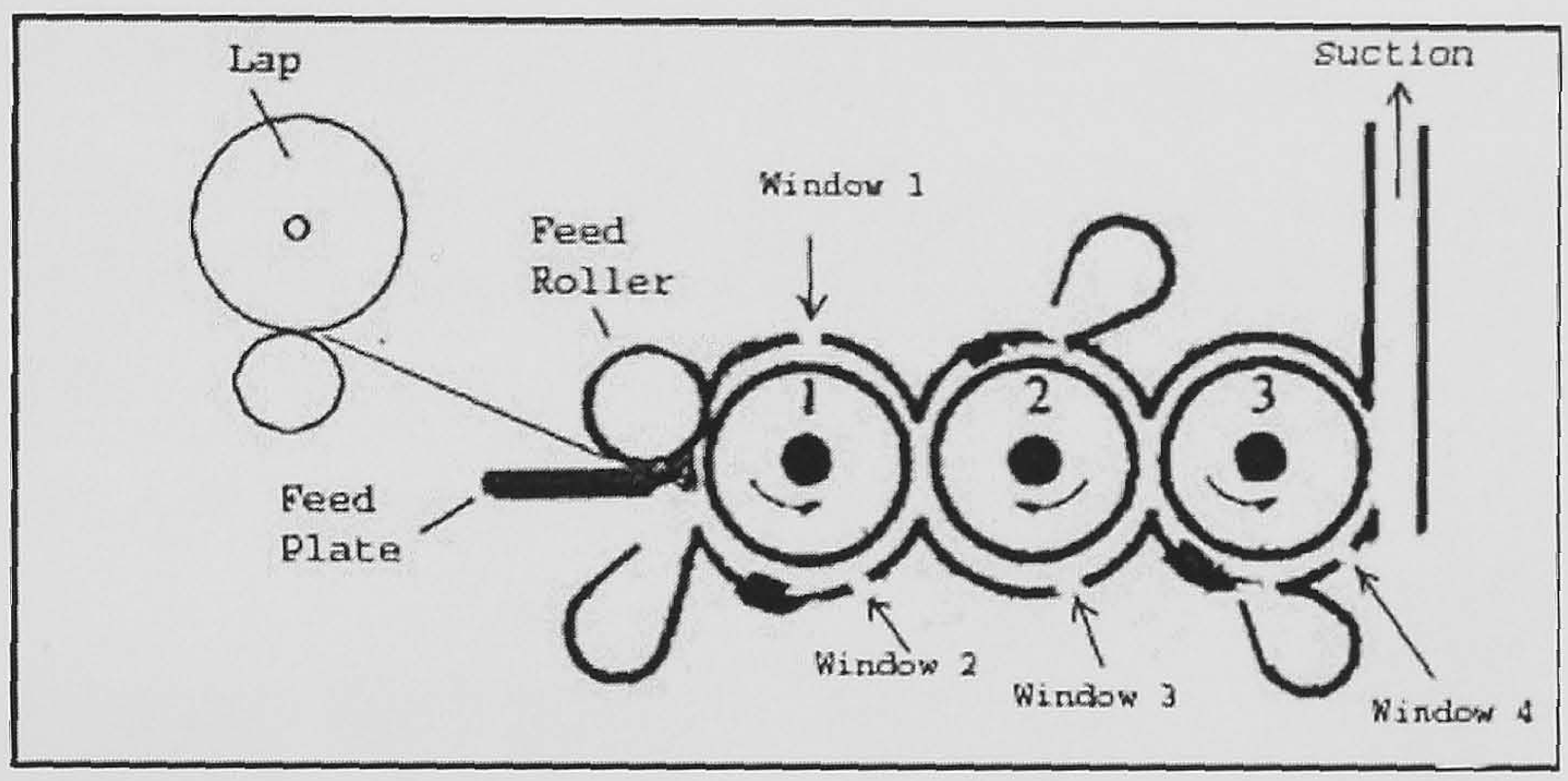


Figure 5.2: Triple licker-in arrangement with suction arrangement

5.3 *Results and Discussion*

The results of the investigations will be discussed with reference to the following:

1. Visual observations of the fibre and tuft flow and
2. Observations based on image processing.

5.3.1 Visual Observations of the fibre flow

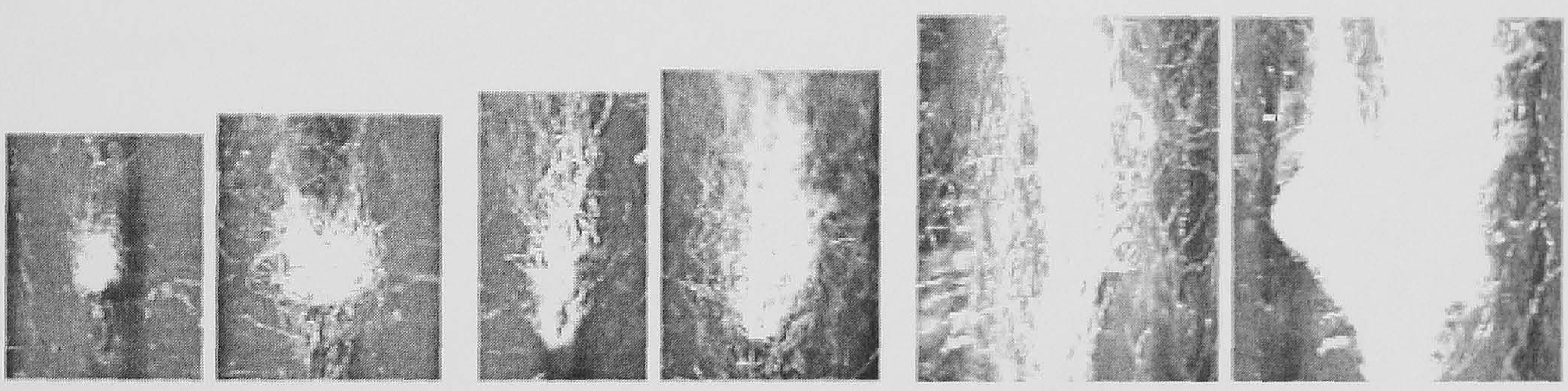
A visual examination of the fibre flow offers an interesting picture of the fibre and tuft dispositions on the licker-in surfaces. The observations recorded included fibre orientation, the amount and sizes of tufts and extent of opening. For every single and triple licker-in experiment, four thousand captured images (randomly selected from 32000 frames recorded) were analysed to identify differences at a macro level.

To bring more objectivity into this otherwise subjective analysis, fibre tufts were classified according to their length:

Fibre tufts smaller than 3 mm size (nep like faults).
Fibre tufts longer than 3 mm but smaller than 9 mm and
Fibre tufts longer than 9 mm *(longer than the half-frame size of the video image).*

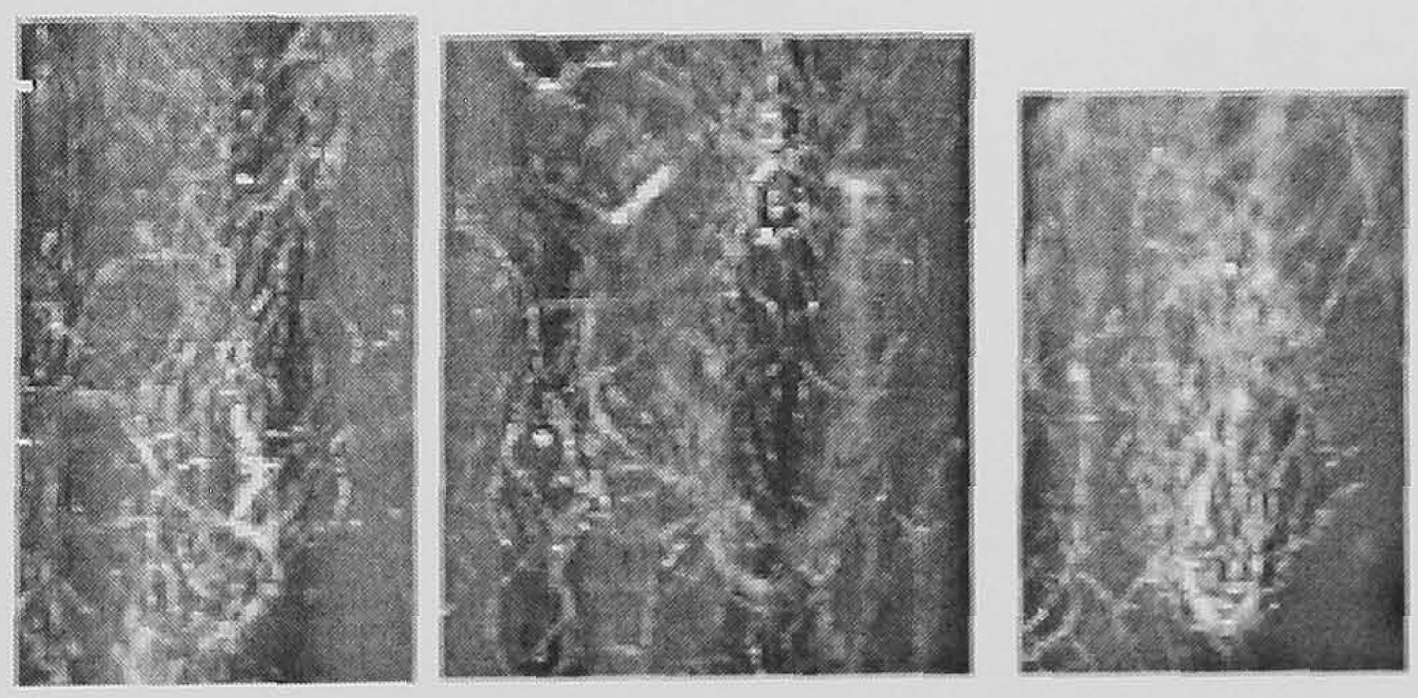
The number of tufts was calculated per 100 milligram or 0.1 gram of material passing through the licker-in.

Figures 5.3 and 5.4 show some of the fibre / tuft configurations observed on the licker-in surfaces.



Nep like faults (< 3mm) Small tufts (3 to 9 mm) Tufts longer than 9mm

Figure 5.3 - Fibre tufts of various sizes



Fairly open clusters A dense cluster

Figure 5.4 – Fibre clusters

5.3.1.1 Single Licker-in

5.3.1.1a Results with NHH 44 cotton

The fibre tuft size distribution at a production rate of 30 kg per hour is shown in Figure 5.5. As the licker-in speed was increased from 840 to 1080 rpm, the number of 3 mm size tufts reduced appreciably while the number of tufts longer than 3 mm remained unchanged. When the speed was further increased to 1440 rpm, a decrease was noticeable in the number of tufts longer than 3mm. Not only did the tufts decrease in number, the tufts were also getting smaller in area accompanied by an increased number of fibre clusters on the surface of the licker-in. It was observed that the fibre cover on the licker-in surface improved noticeably at the highest speed and in general, the individualisation was found to be better than what was achieved at lower speeds. The fibre orientation was average and also did not appear to be affected by increase in licker-in speed.

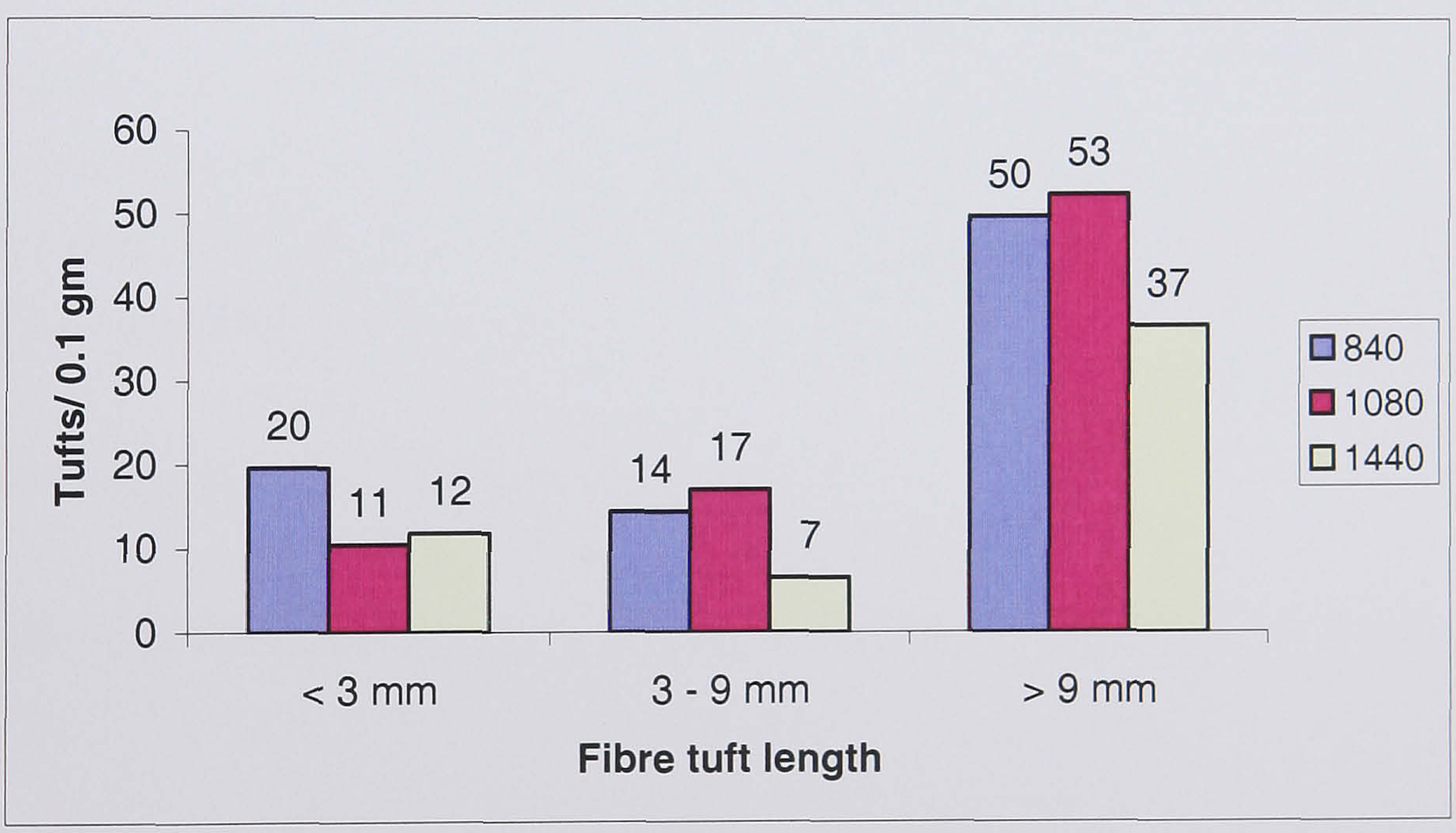


Figure 5.5- Fibre tuft size distribution with single licker-in for NHH 44 cotton

Figure 5.6 shows the fibre tuft size distribution when the production rate was varied between 10 kg per hour and 30 kg per hour at 840 rpm (the optimum speed from the Phase I quality results). The results show that the greatest change in the quantity of larger size tufts occur between production rates of 20 to 30 kg per hour.

The orientation of the fibres and the openness of the fibre mass on the licker-in were found to be fairly good at both 10 and 20 kg per hour, but deteriorated at 30 kg per hour.

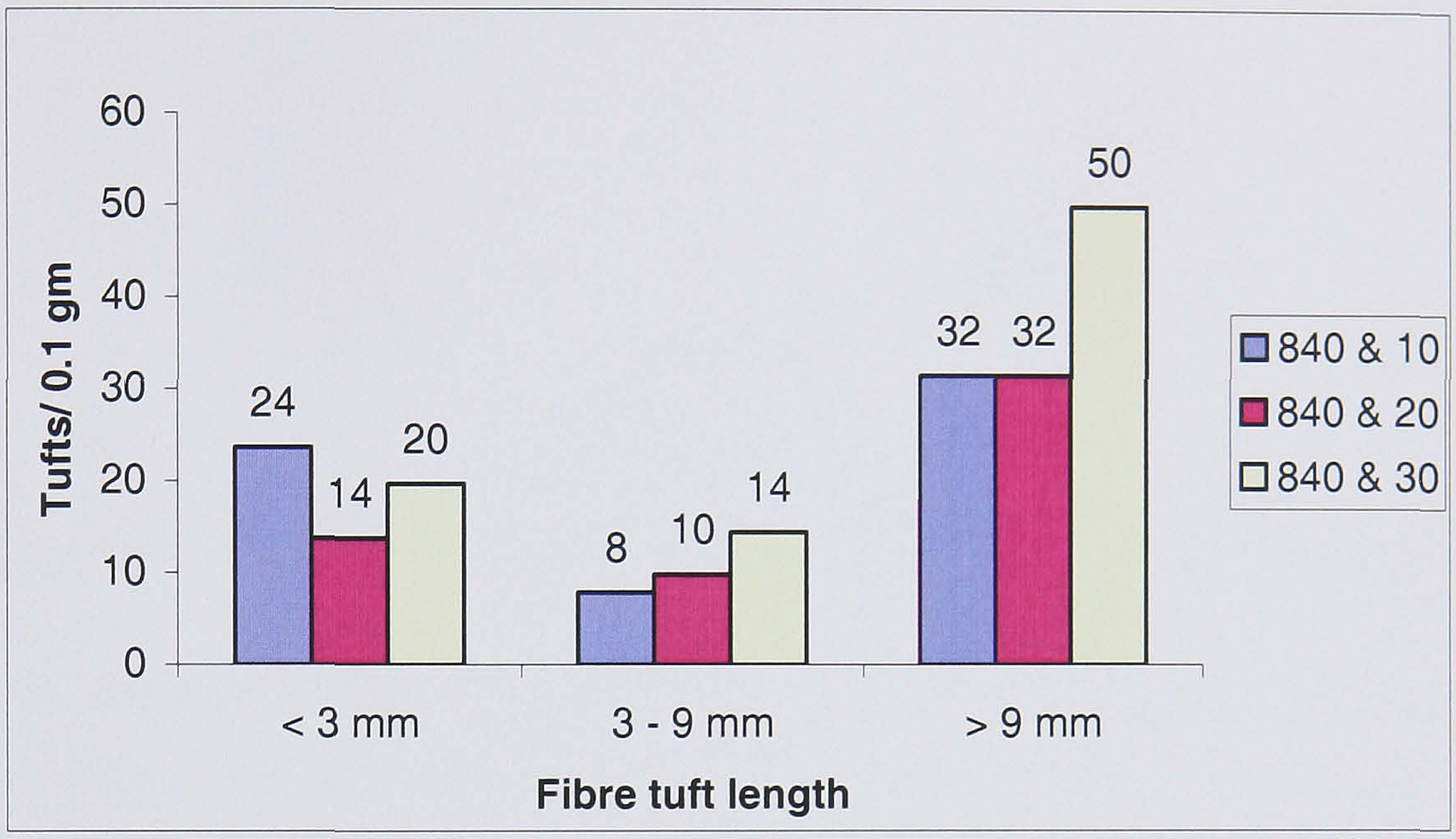


Figure 5.6 - Single Licker-in fibre tuft distribution Vs production rate for NHH 44

In general, it was observed that fibre flow on the single licker-in was not uniform but discontinuous with groups of fibres appearing at irregular intervals. Out of all the licker-in roller speeds used, the best fibre covering on the licker-in was found to occur at the highest speed of 1440 rpm.

5.3.1.1b Results with DCH 32 cotton

The fibre tuft distribution at a production rate of 10 kg per hour is shown in figure 5.7.

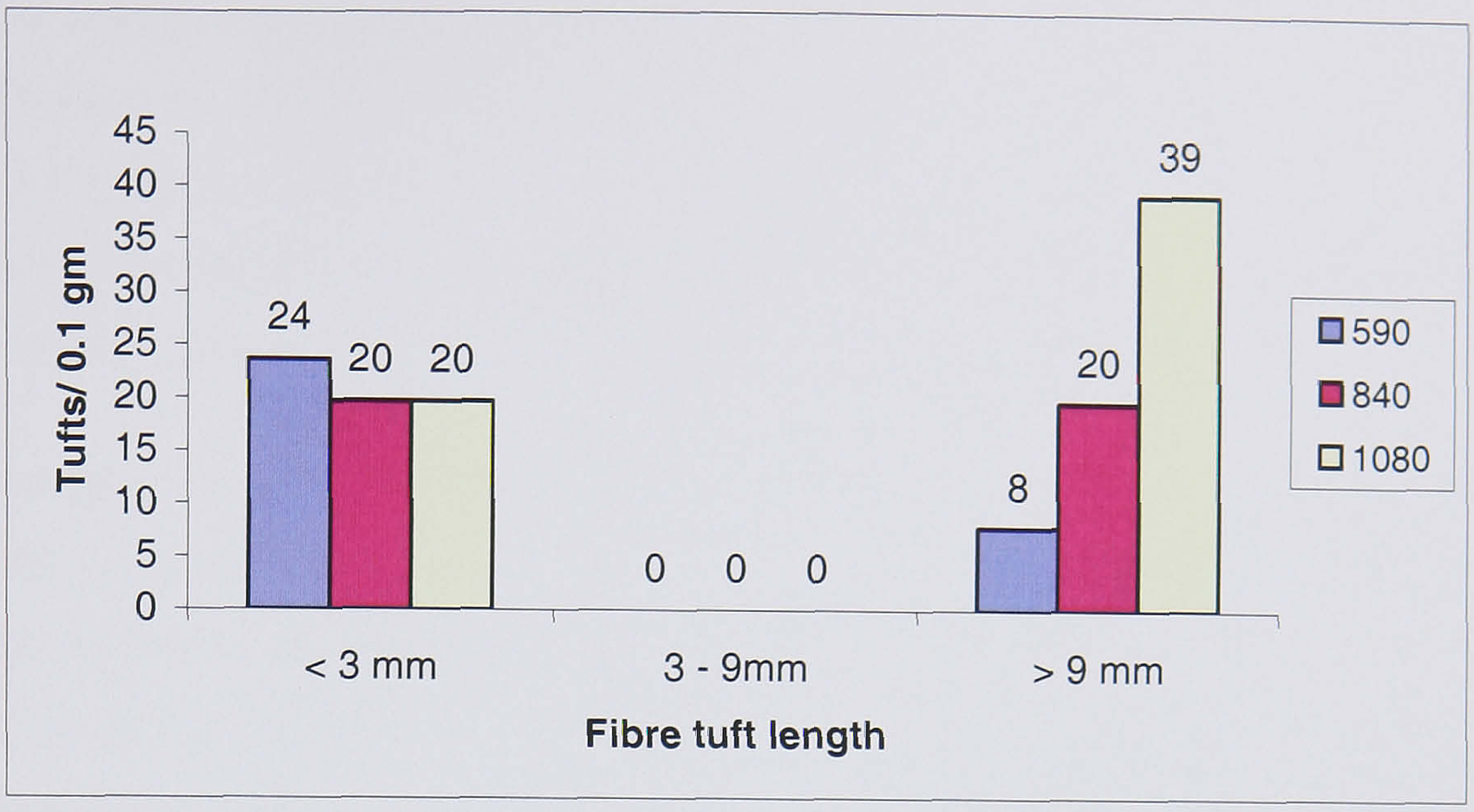


Figure 5.7- Fibre tuft distribution with single licker-in for DCH 32 cotton

Figure 5.7 shows that fibre tufts longer than 9 mm increased as the licker-in speed was increased from 590 rpm to 1080 rpm. This differs from the behaviour of medium staple NHH 44 cotton, where the tufts larger than 9 mm decreased at the highest speed. This is certainly an interesting aspect and is possibly related to the cohesional forces within the lap. For a fibre to be combed out of the feed roller nip, the retention forces at the nip must be overcome by the licker-in. The fibre retention force at the feed roller/ feed plate nip is dependent on the fibre cohesional forces within the lap (CF) and retention forces due to feed roller loading (P). Therefore,

$$\text{Total fibre retention force at the feed nip} \quad \alpha \quad CF + P$$

At low licker-in speeds, the licker-in generates reduced amount of opening forces and so the lap cohesion along with pressure on feed roller aids in fibre retention at the feed roller nip. Therefore, the licker-in carries away mainly fibres or small tufts that are combed out or released from the feed roller nip. At higher licker-in speeds, in a feed matt that has greater cohesional properties, the opening forces generated by the licker-in possibly overcomes the retention forces caused by feed roller pressure before overcoming the fibre frictional forces within the lap. Thus fibre tufts are pulled out of the feed roller nip resulting in a greater number of unopened tufts. Being a fine and extra-long fibre, DCH 32 cotton ought to have greater cohesional properties than the medium staple, medium fine NHH 44 and therefore, its behaviour is different from that of the NHH 44 cotton. With NHH 44 cotton even at the highest speed used, the fibre tufts on the licker-in are reduced because the fibre opening forces generated by the licker-in overcome the inter-fibre friction before overcoming the retention forces due to feed roller loading.

Surprisingly, fibre tufts at 3-9 mm size were not found on the licker-in surface at all licker-in speeds at 10 kg per hour. Fibre clusters increased with an increase in licker-in speed for DCH cotton, which is similar to NHH 44 cotton. These clusters appear to be well opened and smaller in size as the licker-in speed was increased. The fibre orientation also appeared to improve as the licker-in speed was increased from 590 to 1080 rpm.

Figure 5.8 shows the fibre tuft size distribution with change in production rates. At 840 rpm (the optimum speed from quality results), the production was increased from 10 kg per hour to 20 kg per hour. The graph shows that the fibre tufts (except < 3mm tufts) increased considerably with the production rate. Also, the orientation of the fibres on the licker-in was found to deteriorate to a certain degree with an increase in production rate, while the openness of the fibre mass on the licker-in remained fairly good at all production rates.

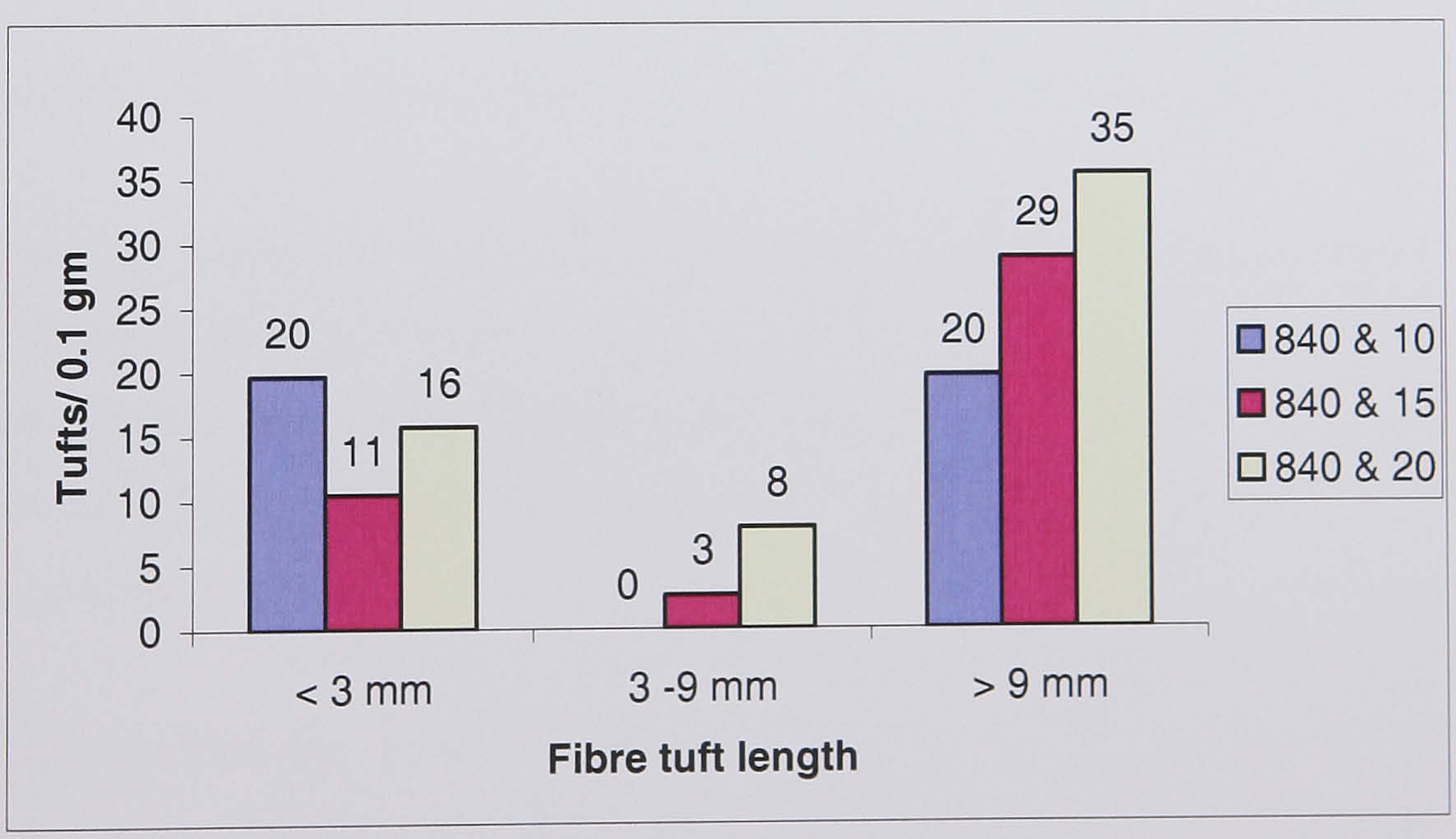


Figure 5.8 - Single Licker-in fibre tuft size distribution vs. production rate for DCH 32

5.3.1.2 Triple Licker-in

To study the progress of fibre opening from the first to the third roller, fibre tuft size distribution and fibre orientation were observed on the first licker-in roller (roller adjacent to feed roller) and the third licker-in roller (feeding main cylinder). The observations with the triple licker-in are discussed below.

5.3.1.2a Results with NHH 44 cotton

Figure 5.9 shows the fibre tuft size distribution on the third licker-in roller.

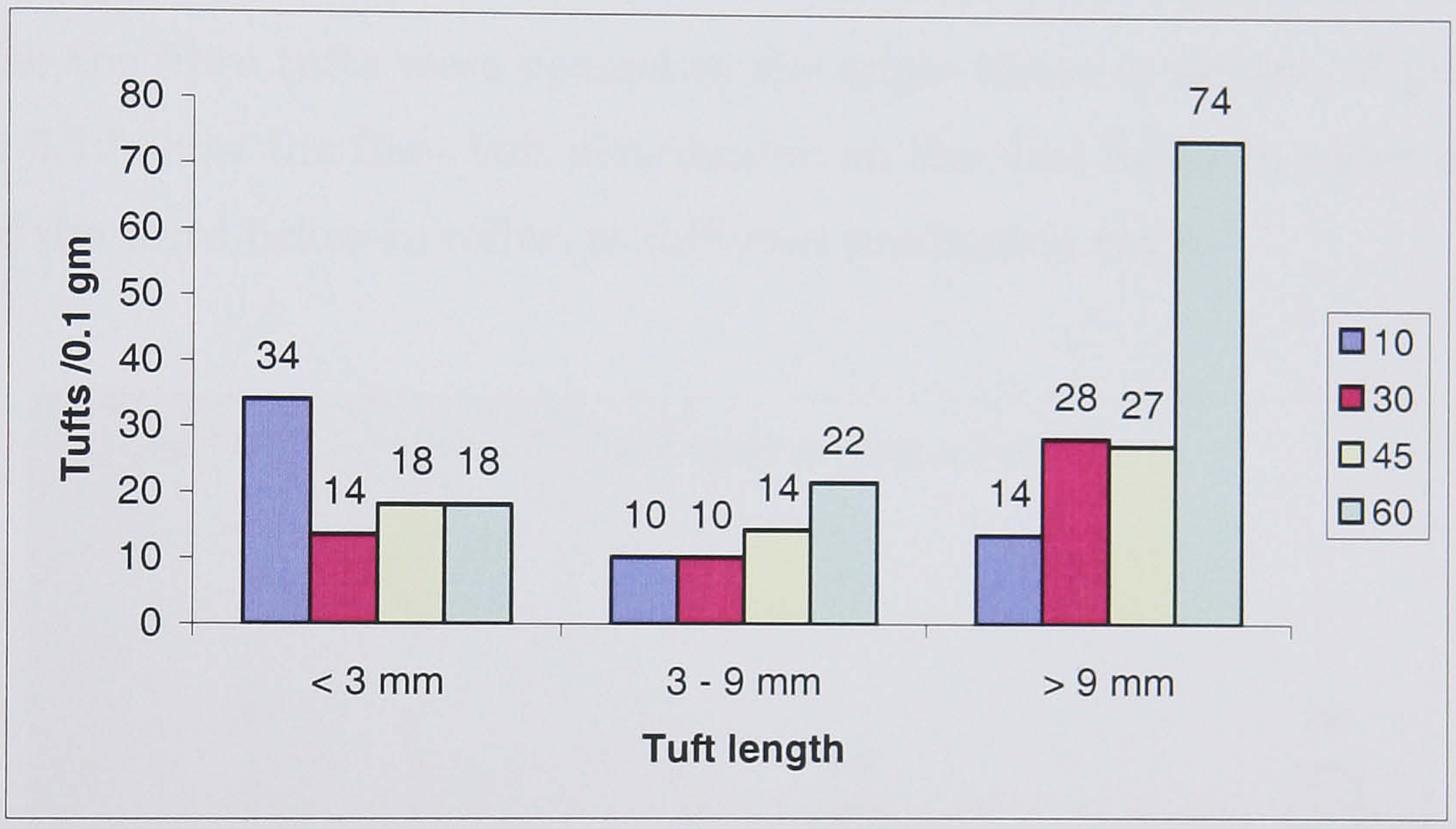


Figure 5.9: NHH 44 - Fibre tuft size distribution with Triple Licker-in (Roller 3)

As Figure 5.9 shows, the tufts were fewer in number at the lowest production rate (except 3 mm size tufts). There was an increase in the size of larger tufts (>9mm) when production was increased from 10 to 30 kg per hour. The biggest increase in the number of large tufts was seen when the production was increased from 45 kg to 60 kg per hour.

Fibre individualisation (visual impression) was found to be excellent at the lowest production rate, though many fibres were poorly oriented to the direction of flow. At this production rate, a number of small, well-opened fibre clusters were seen. When the production rate was increased to 30 kg /hour, the number of fibre clusters showed a decrease and many clusters were larger in size but were still well opened. Again it was observed that the fibre orientation was bad, but the individualisation of fibres was still good. Beyond 45 kg per hour, the deterioration was clearly visible in terms of individualisation and the number of fibre clusters that were dense. The fibre tufts were bigger, longer or elongated compared to the observations at 10 kg and 30 kg /hour. The stationary flats in the licker-in zone perhaps could not cope with such high throughput rates resulting in them becoming clogged with fibre tufts and they became ineffective at opening the incoming tufts.

Fibre tuft sizes were compared at 3 production rates on both the rollers in order to study how the fibre tufts were opened in the triple licker-in system. Figures 5.10, 5.11 and 5.12 show the fibre tuft distribution on the first licker-in roller compared to that of the third licker-in roller, at different production rates.

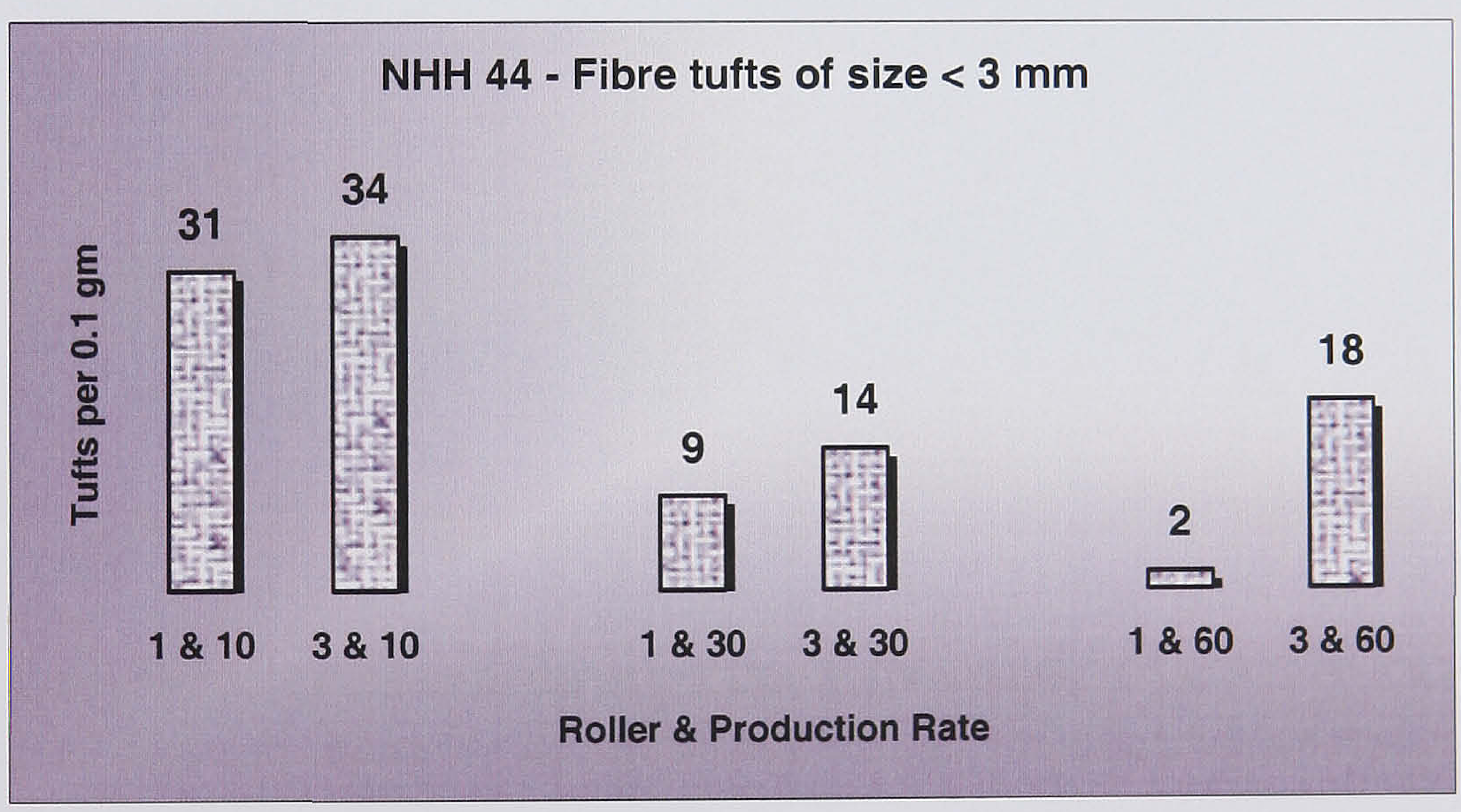


Figure 5.10 – Fibre tufts < 3 mm size with triple licker-in for NHH 44

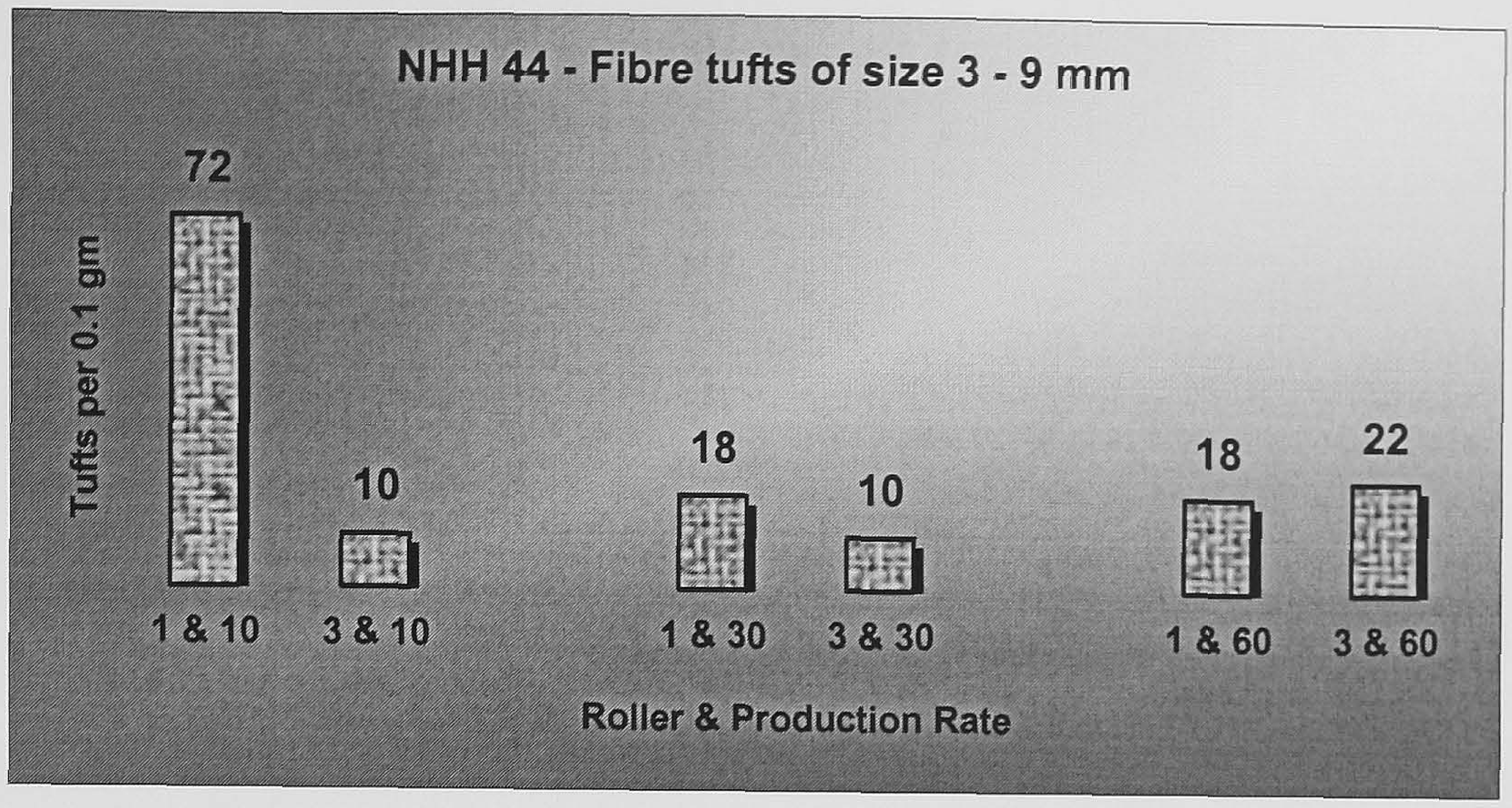


Figure 5.11 – Fibre tufts 3 – 9 mm size with triple licker-in for NHH 44

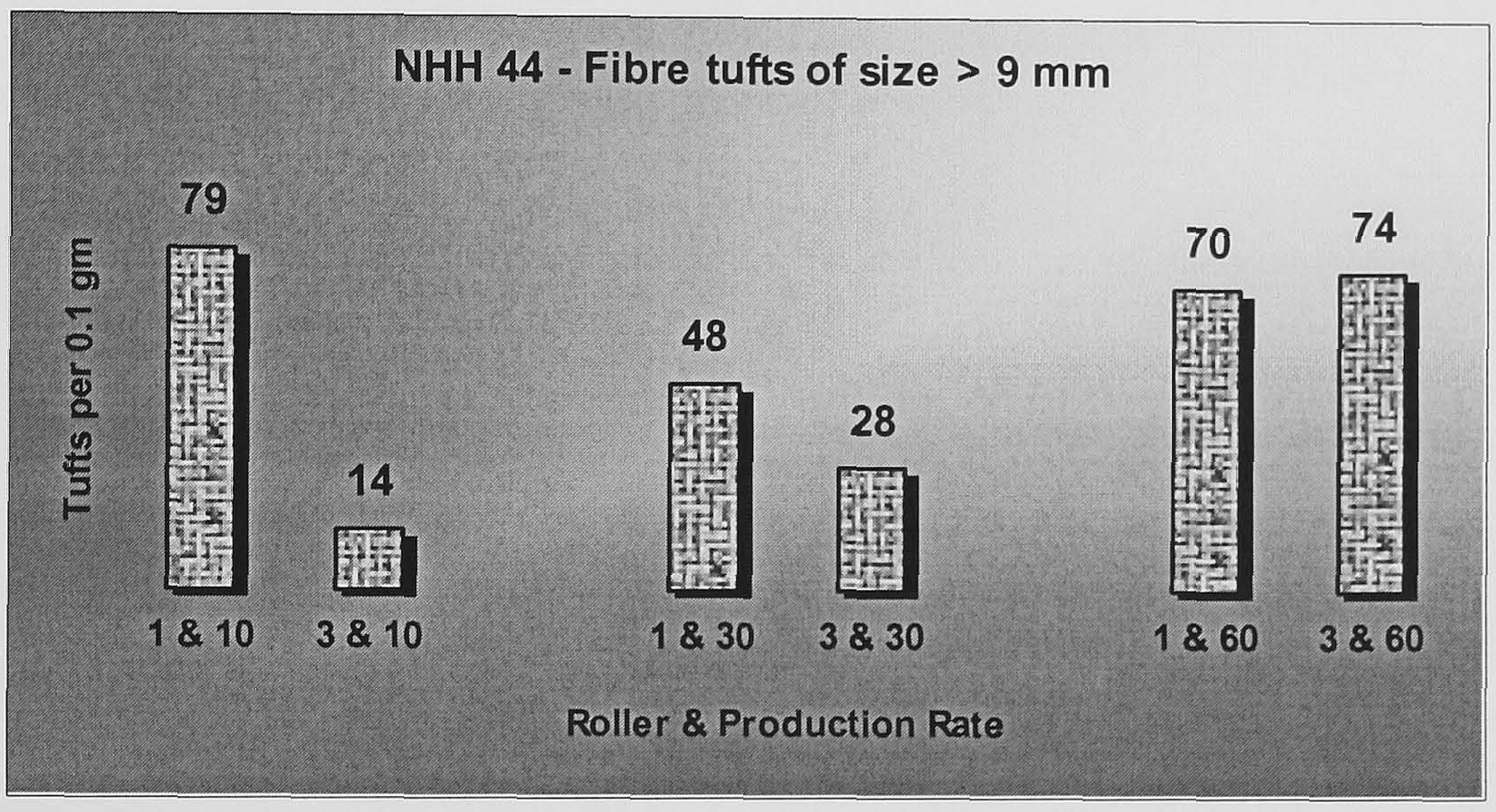


Figure 5.12 – Fibre tufts > 9 mm size with triple licker-in for NHH 44

On the first roller of the triple licker-in, the tufts longer than 9 mm did not show any particular trend with reference to the production rate while tufts smaller than 9 mm decreased in number as the production rate was increased. However, what was significant was that even though tufts longer than 9 mm were similar in number at 10 and 60 kg per hour, at 60 kg per hour the tufts were much larger in size, possibly due to the drastic reduction of draft at the feed roller-feed plate nip. The orientation of the fibres and fibre individualisation on the first roller was fairly good at production rates of 10 kg and 30 kg per hour and deteriorated at 60 kg per hour.

A remarkable picture emerges when the number of tufts of each size category was compared between the first and third rollers. Tuft sizes of less than 3 mm showed an increase from the first roller to the third roller, which means that many of the tufts in this category were newly created from the tufts longer than 3 mm. The fibre tufts longer than 3 mm seen on the first roller decreased in number on the third roller up to a production rate of 30 kg per hour. However, at the highest production rate of 60 kg per hour, these tufts (longer than 3 mm) were similar in number on both rollers. The possible reason for this could be that at high production rates like 60 kg per hour, the stationary flats cannot efficiently break down the large size tufts (created because of the lower draft at the feed roller-feed plate nip) at high throughput rates, thus large numbers of big size tufts are still present in the material presented to the main cylinder.

5.3.1.2b Results with DCH 32 cotton

Figure 5.13 shows the fibre tuft sizes on the third licker-in for the DCH 32 cotton.

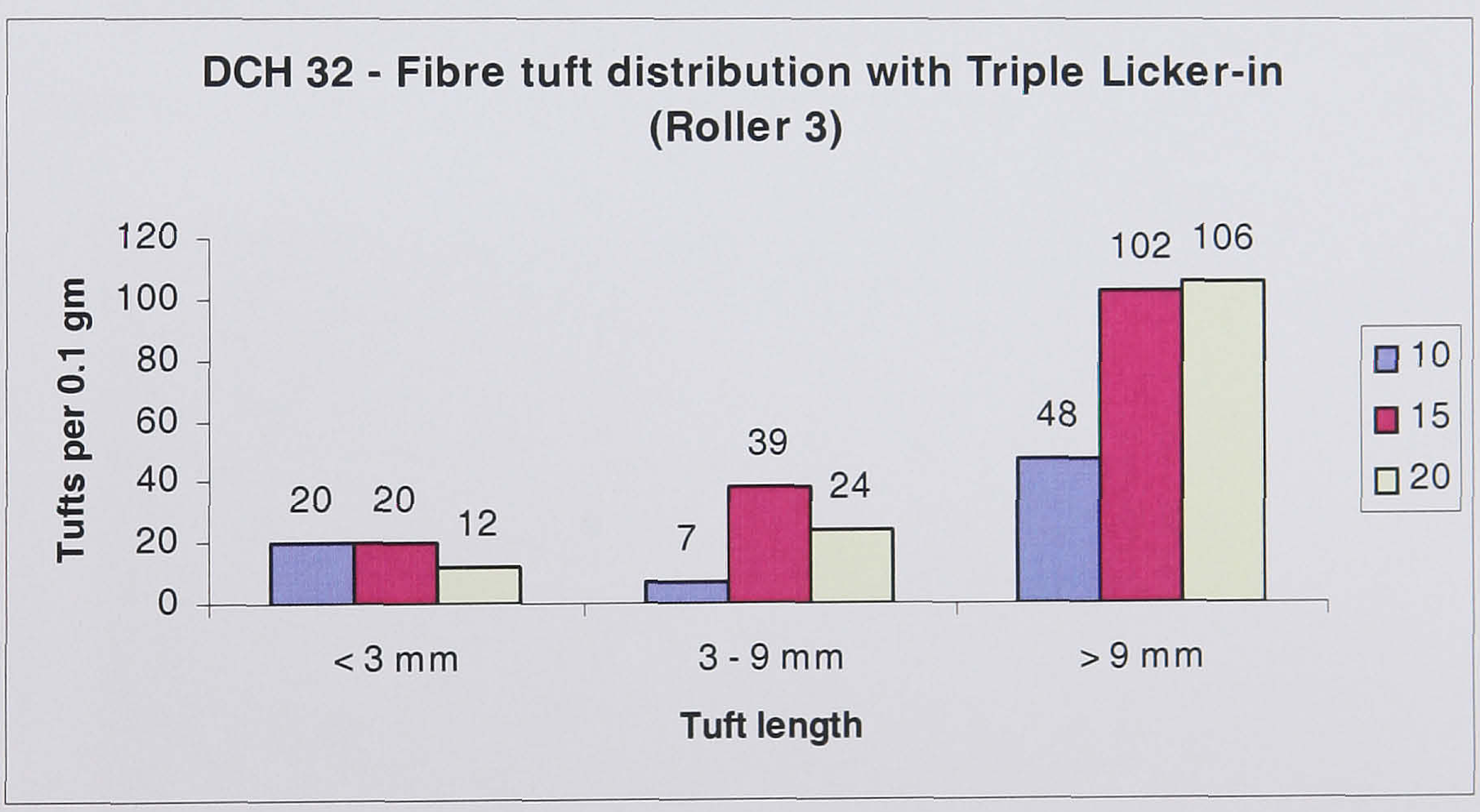


Figure 5.13: DCH 32 - Fibre tuft distribution with Triple Licker-in (Roller 3)

It is seen from Figure 5.13 that tufts longer than 3 mm showed a large increase in number when the production rate was increased from 10 to 15 kg per hour. Further, it was observed that the tufts were very elongated running into several frames (video frames) at production rates of 15 kg and 20 kg per hour.

At the lowest production rate of 10 kg per hour, fibre individualisation (visual impression) was found to be good. Like the NHH 44 cotton, the DCH 32 cotton showed poor orientation of the fibres on the third licker-in. Fibre individualisation and orientation appeared to deteriorate as the production rate was increased beyond 10 kg per hour.

Comparisons of tuft distributions on the first roller with the third roller are shown in Figures 5.14, 5.15 and 5.16.

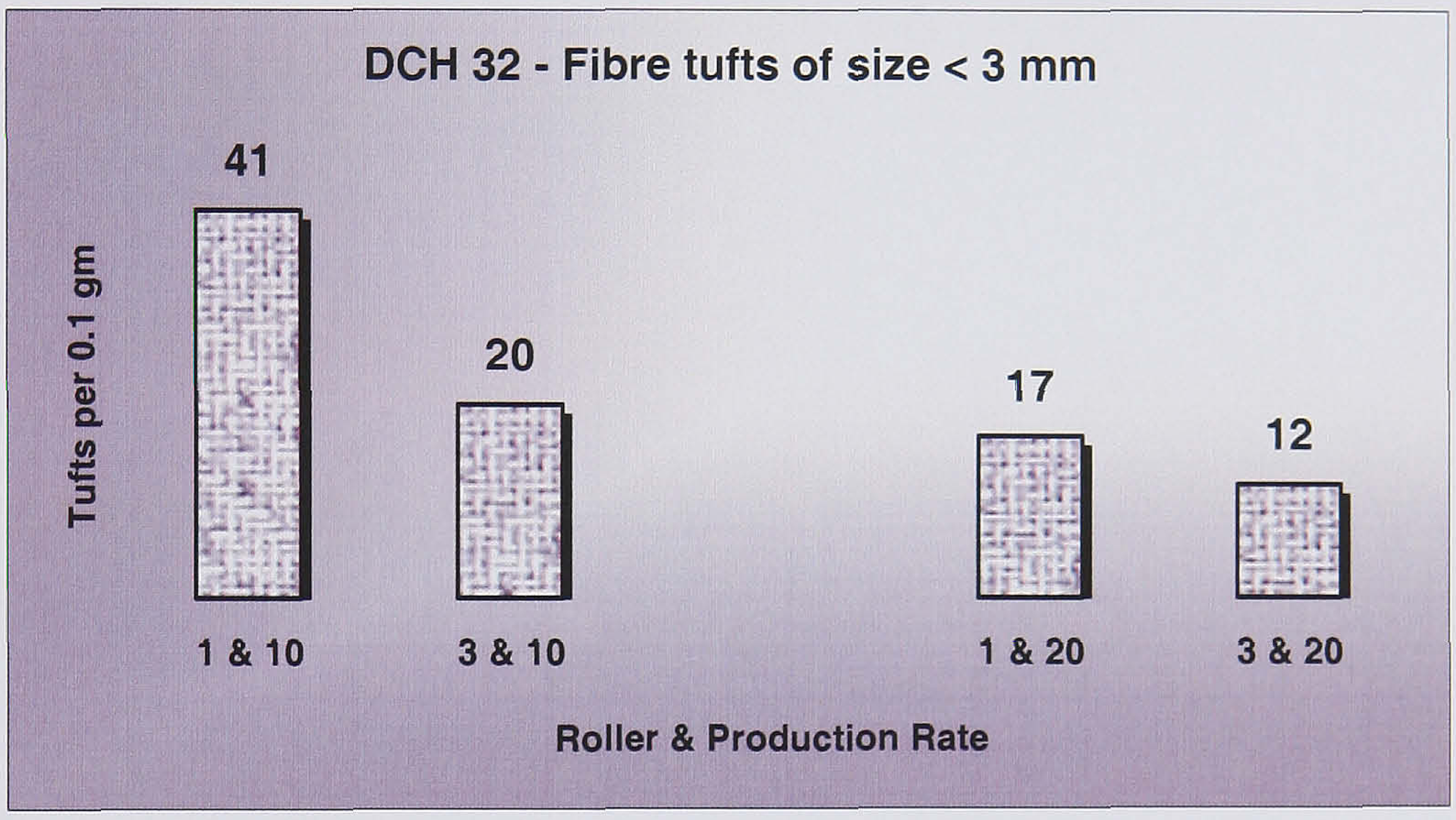


Figure 5.14 – Fibre tufts < 3 mm size with triple licker-in for DCH32

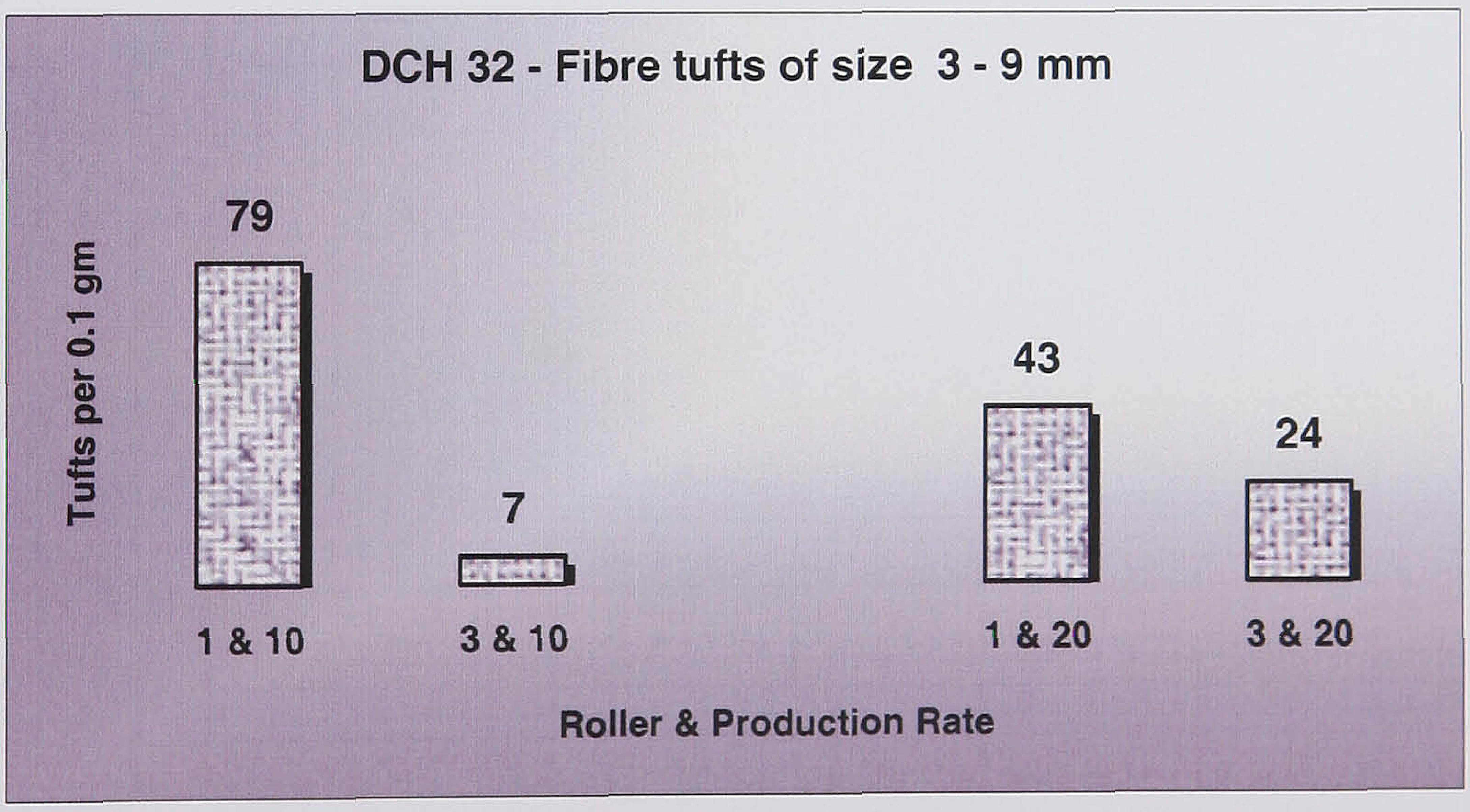


Figure 5.15– Fibre tufts 3 –9 mm size with triple licker-in for DCH32

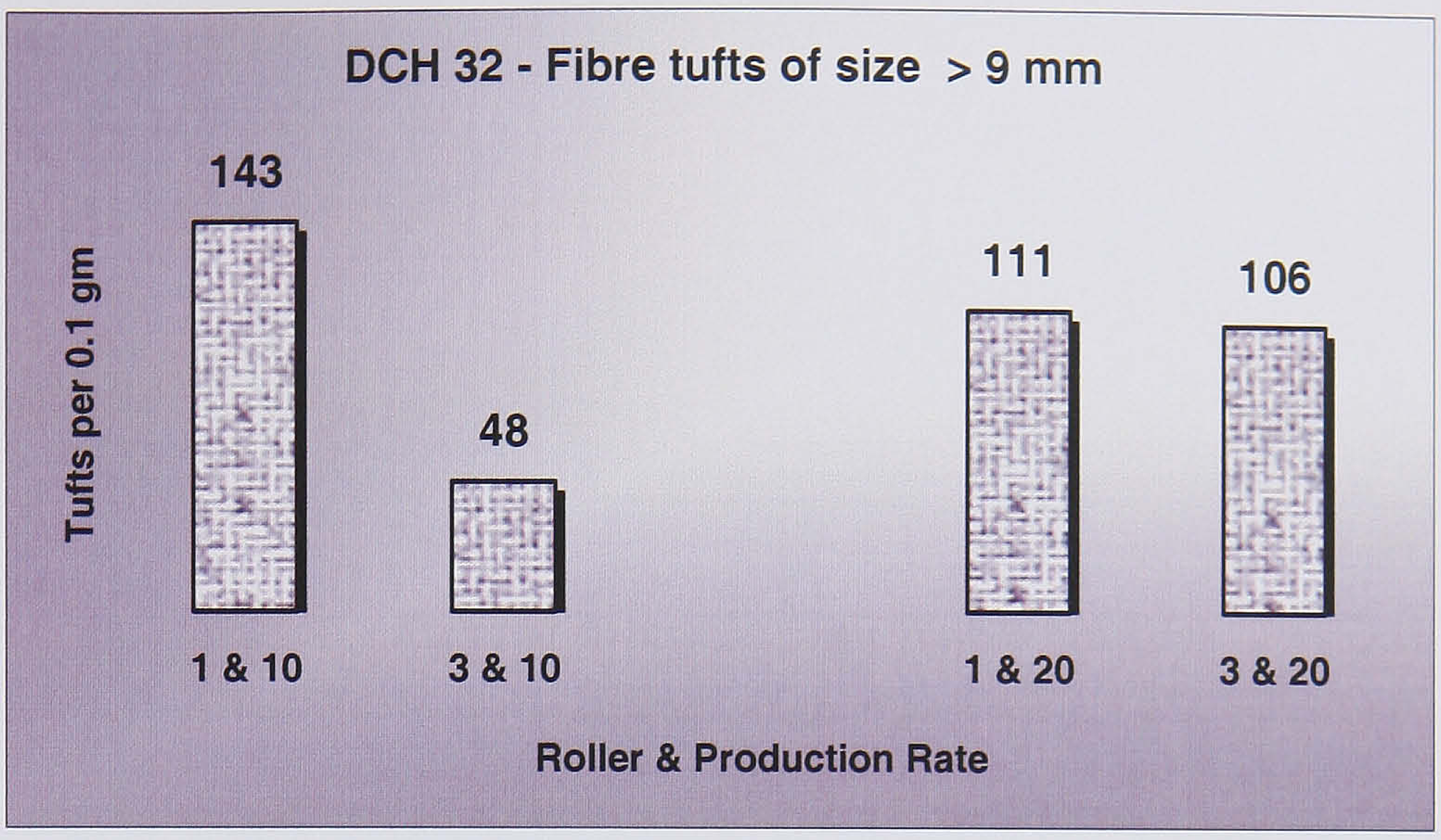


Figure 5.16 – Fibre tufts > 9 mm size with triple licker-in for DCH32

As Figs 5.14 to 5.16 show, fibre tufts of all sizes decreased on the first roller of the triple licker-in as the production rate was increased from 10 to 20 kg per hour. The reduced number of tufts does not mean an improvement in opening when the production rate is increased. The tufts though less in number (> 9 mm) were large in size and the reduction in smaller size tufts (< 9 mm) only mean decreased opening at the first licker-in because of doubling of the feed rate.

The fibre tufts of up to 9 mm in length seen on the first roller decreased on the third roller at both production rates due to the opening of the tufts by the stationary flats on the second and third rollers. However, the tufts longer than 9 mm were similar in number on the first and third rollers at 20 kg per hour. As discussed before, large size tufts are seen on the first licker-in roller due to reduction in opening at the feed roller-feed plate nip. These tufts are not fully opened at the stationary flats, but rather get elongated, possibly because the cohesional properties are quite high for this long and fine DCH 32 cotton. Most of the longer group of tufts (> 9 mm) were found to be elongated tufts at 20 kg per hour.

5.3.1.3 Comparison of Single and Triple Licker-in systems

It is important to compare the fibre tuft distributions between single and triple licker-in systems at a given production rate to establish the differences between the two licker-in systems. For the purpose of comparison, the single licker-in speed at which the best quality results (840 rpm) were obtained in Phase I investigation is compared to results with triple licker-in (on the third roller) at the same production rates. Only the lowest and the highest production rates with single licker-in (10 and 20 kg per hour) are compared for DCH 32 cotton with triple licker-in at the same production rates. Similarly for NHH 44, lowest and highest production rates with single licker-in (10 and 30 kg per hour) are compared with triple licker-in (on the third roller) at the same production rates.

Figure 5.17 shows the tuft distributions with single and triple licker-in systems for DCH 32 cotton. It is seen that except tufts of 3 mm size, the number of tufts are greater with triple licker-in at both 10 and 20 kg production rates. The number of tufts increases dramatically at 20 kg per hour production rate meaning a significant deterioration in the opening with triple licker-in. Not only did the number of tufts increase but many of the tufts were found to be long and elongated tufts. This establishes that for long and fine cottons (with higher inter-fibre cohesion), opening with single licker-in is superior to the triple licker-in. In addition, the fibre orientation was found to be poor with triple licker-in and better with single licker-in at both production rates (some deterioration at 20 kg/hr).

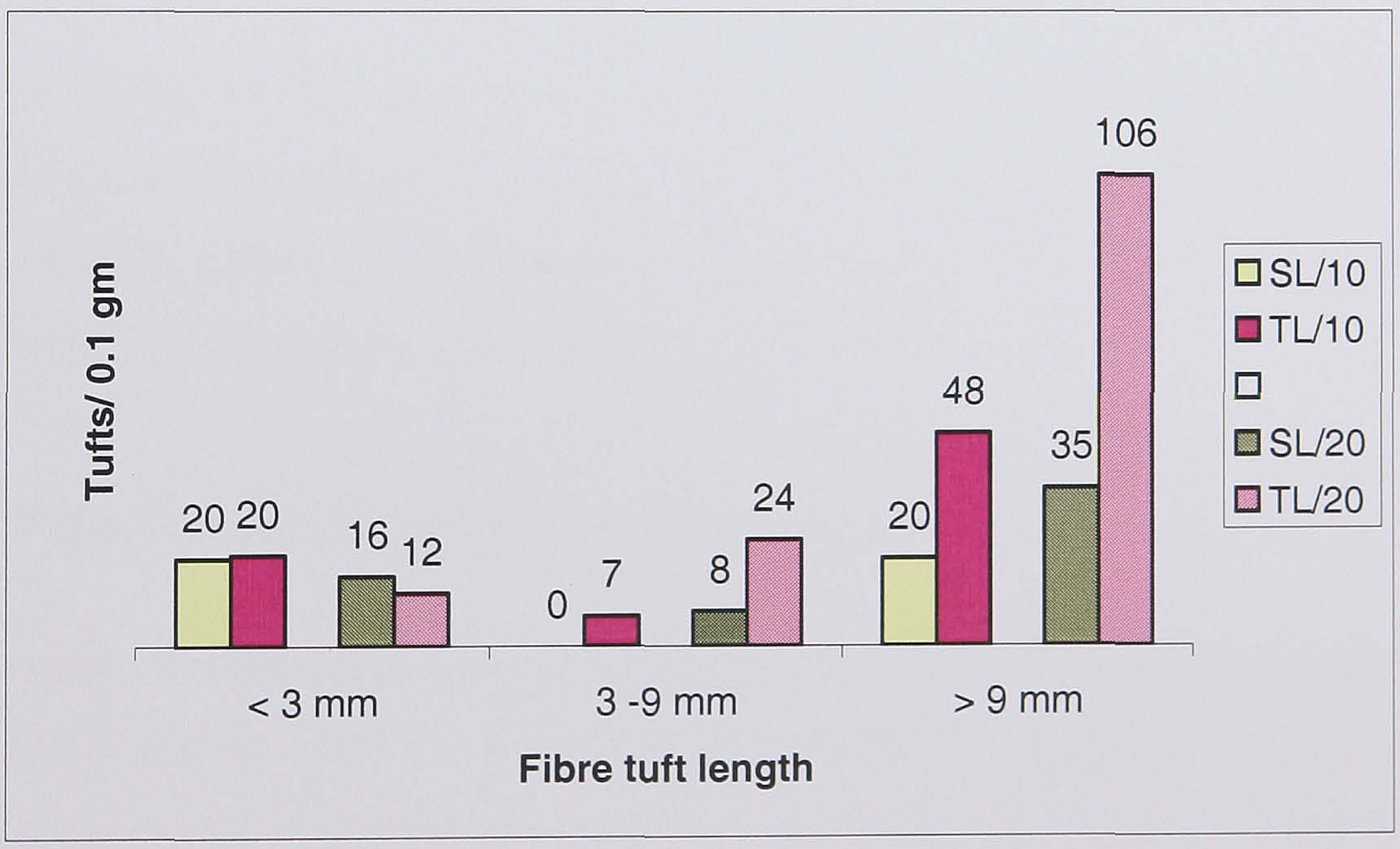


Figure 5.17: DCH 32 - Fibre tufts distribution with single and triple licker-in arrangements

Figure 5.18 compares the fibre tuft distribution for NHH 44 cotton. It is seen that the number of tufts longer than 9 mm size show a decrease at 10 kg per hour with triple licker-in. Interestingly, at 30 kg per hour, tufts of all sizes show a decrease with triple licker-in when compared to single licker-in. For cotton with lower cohesion, triple licker-in is seen to fare better and it appears that the opening at the stationary flats is superior to opening at feed roller nip for such cotton.

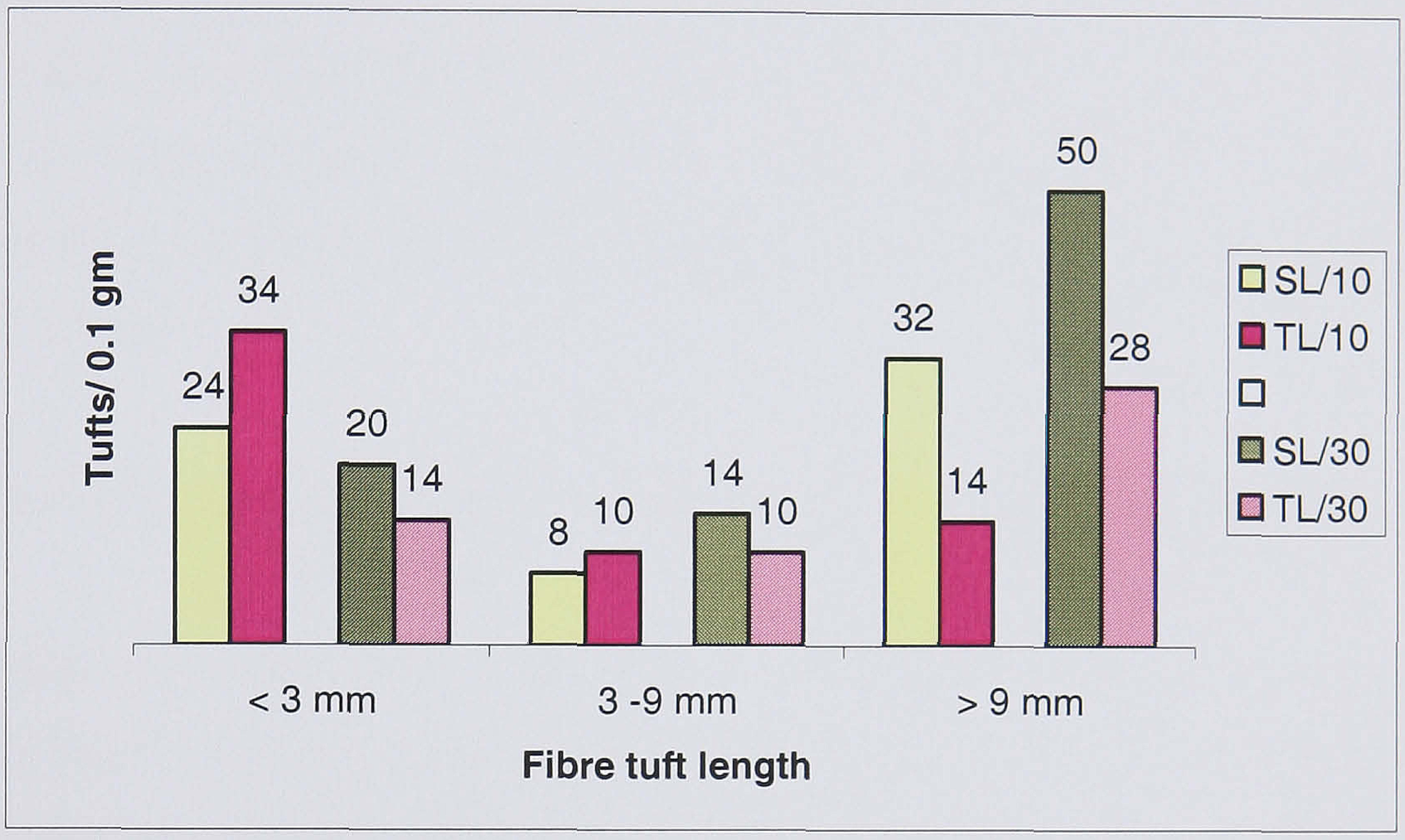


Figure 5.18 - NHH 44 - Fibre tufts distribution with single and triple licker-in arrangements

In case of NHH 44, the orientation was again poor with triple licker-in though individualisation was good at both production rates, when compared to single licker-in. Single licker-in showed good fibre orientation at 10 kg per hour and it deteriorated to some extent at 30 kg per hour.

5.3.1.4 Fibre recycling on the licker-in rollers

In this study, it was found that some fibres and tufts were recycling on the first and second licker-in rollers. Therefore the amount of fibres and tufts recycled on the first and second rollers had to be estimated (from the visual impressions made). This study was based on high-speed photography through windows 1 and 3 (Figure 5.2, page 155).

On the first roller, it was observed that only a small number of fibres and tufts recycled on the licker-in surface for both cotton varieties and also the recycling material seemed to increase proportionately with the production rate.

On the second roller, a slightly greater amount of fibres were found to recycle than on the first roller for the NHH 44 cotton. However, for the DCH 32 cotton, a large amount of fibres were found to recycle on the second licker-in. The exact effect of this recycling of fibres on fibre and yarn quality is not known. However, it can be assumed that the recycling of these fine and long fibres may lead to increased disorder and disorientation of the fibres presented to the cylinder, which in turn could significantly influence the carding performance and the fibre configurations in the card sliver.

5.3.2 Results from Image Processing of the captured fibre images

As discussed in section 5.2.4, images of the fibre flow were captured on the single and triple licker-in surfaces using high-speed photography and the fibre disposition on the licker-in surfaces (fibre extent and orientation) was studied from the captured fibre images using Image Pro Plus, image analysis software. Table 5.4 gives the sample size used for each test. As seen from the table, for the important tests a sample size of 50 fibres was used instead of a sample size of 25 fibres. A larger sample size was used on the single and triple licker-in parameters that gave best fibre and yarn quality test results because they were considered the main experiments and therefore merited a larger sample size in order to affirm with confidence if there were any changes in fibre configuration.

Each set of experiments generated either 16000 frames (full frames) or 32000 frames (half frames). Of these, five thousand frames were selected randomly and recorded for each experiment. The frame number from which a single fibre was to be selected for the analysis was determined using a random number generator program downloaded from the Internet [95] (written by Windy Weaver and Mike Raulin). A single fibre could span anywhere from one to five frames. Only those fibres that were clearly visible (full lengths) were traced. Where it was not possible to identify a clear fibre in the selected frame, as was the case most of the time, subsequent frames were checked and the clearest fibre was selected and traced. Even though the fibres selected could not fully represent all the fibres that passed through the licker-in, it was expected that a fair indication would be obtained of the nature of changes that occur to the fibre disposition on licker-in surfaces when licker-in parameter or design was changed.

Table 5.4: Sample size for Single and Triple Licker-in tests

Cotton	Licker-in type	Licker-in Speed	Production in Kg/ hr	Sample size
DCH 32	Single	590 rpm	10	25
		840 rpm	**10**	**50**
		1080 rpm	10	25
		840 rpm	20	25
	Triple	*	**10**	**50**
			15	25
			20	25
NHH 44	Single	**840 rpm**	**30**	**50**
		1080 rpm	30	25
		1440 rpm	30	25
		840 rpm	10	25
	Triple	**	**30**	**50**
			45	25
			60	25

* The Triple licker-in speeds in rpm (rolls 1,2,3) were 755, 1202 and 1516 respectively

** The Triple licker-in speeds in rpm (rolls 1,2,3) were 998, 1568, and 2067 respectively

Image Pro Plus software (Media Cybernetics) was used to determine the following parameters.

1. Fibre extent
2. Fibre length
3. Fibre Projection in X-direction
4. Fibre Projection in Y-direction (or the machine direction)
5. Orientation of the fibre in the machine direction and
6. Fibre Extent Ratio (FER).

The fibre extent ratio (FER) was calculated from the following formula.

$$\text{Fibre Extent Ratio \%} = \frac{(\text{Fibre length} - \text{Fibre Extent}) \times 100}{\text{Fibre Extent}}$$

The term FER has been used again in this study as many of the fibres on the licker-in exhibit several other configurations apart from being crimped. Therefore, the term 'Crimp Ratio' is not an apt term to be used in this investigation.

The fibre configurations on licker-in for the main licker-in parameters with single and triple licker-in (highlighted ones in Table 5.4) are given in Table 5.5.

Table 5.5: Fibre configurations on single (SL) and triple licker-in (TL) surfaces for important licker-in parameters

Cotton	Licker-in type	Kg/hr	Mean Fibre Length mm	Mean Fibre Extent mm	Mean FER %	Mean Fibre Projn. -X in mm	Mean Fibre Projn. - Y in mm	Mean Orientation (Degrees)
DCH 32	SL -840 rpm	10	28.8	21.2	25.9	3.5	21.1	4.9
	TL	10	23.3	15.1	34.4	5.5	17.2	16.7
NHH 44	SL -840 rpm	30	26.0	18.4	28.1	4.7	17.9	9.7
	TL	30	24.1	15.6	34.5	4.5	15.8	12.4

As can be seen from Table 5.5, the Fibre Extent was greater with the single licker-in for both cotton varieties at the same production rates. The FER was greater with the triple licker-in and the fibre orientation in the machine direction was significantly different between the two licker-in systems. With triple licker-in, the orientation angle was much higher for the long DCH 32 cotton. Even though the differences in orientation are not as great as with the fine cotton, it was certainly greater with triple licker-in for the medium NHH 44 cotton. A change to the mean values of fibre projections in the X and Y direction only confirms the changes in fibre orientation. The results of FER and orientations with both cotton varieties were found to be significantly (95% confidence limits) different between the single and triple licker-in systems.

Figure 5.19 shows the fibre orientations in the machine direction with both licker-in arrangements.

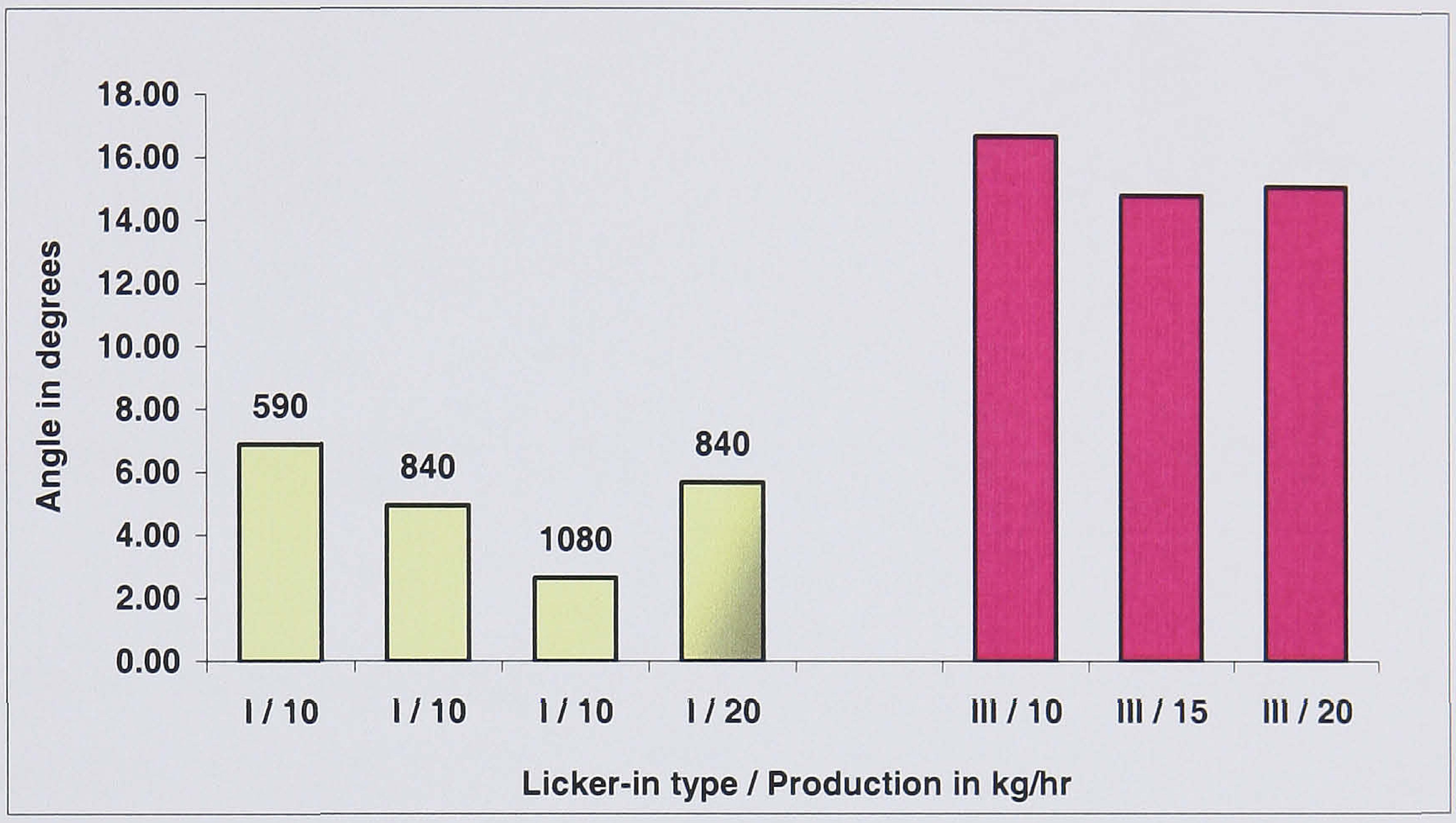


Figure 5.19 – Fibre orientation with single and triple licker-in arrangements for DCH 32

It can be seen that the fibre orientation on the licker-in improved as the licker-in speed was increased from 590 to 1080 rpm for the single licker-in. Also deterioration is noticed in fibre orientation when the production rate was increased from 10 to 20 kg per hour at 840 rpm. It is apparent that the fibres on the triple licker-in displayed greater disorientation compared to single licker-in and an increase in production rate seemed to improve the orientation slightly.

Figure 5.20 shows the fibre orientation with the two licker-in arrangements for NHH 44 cotton.

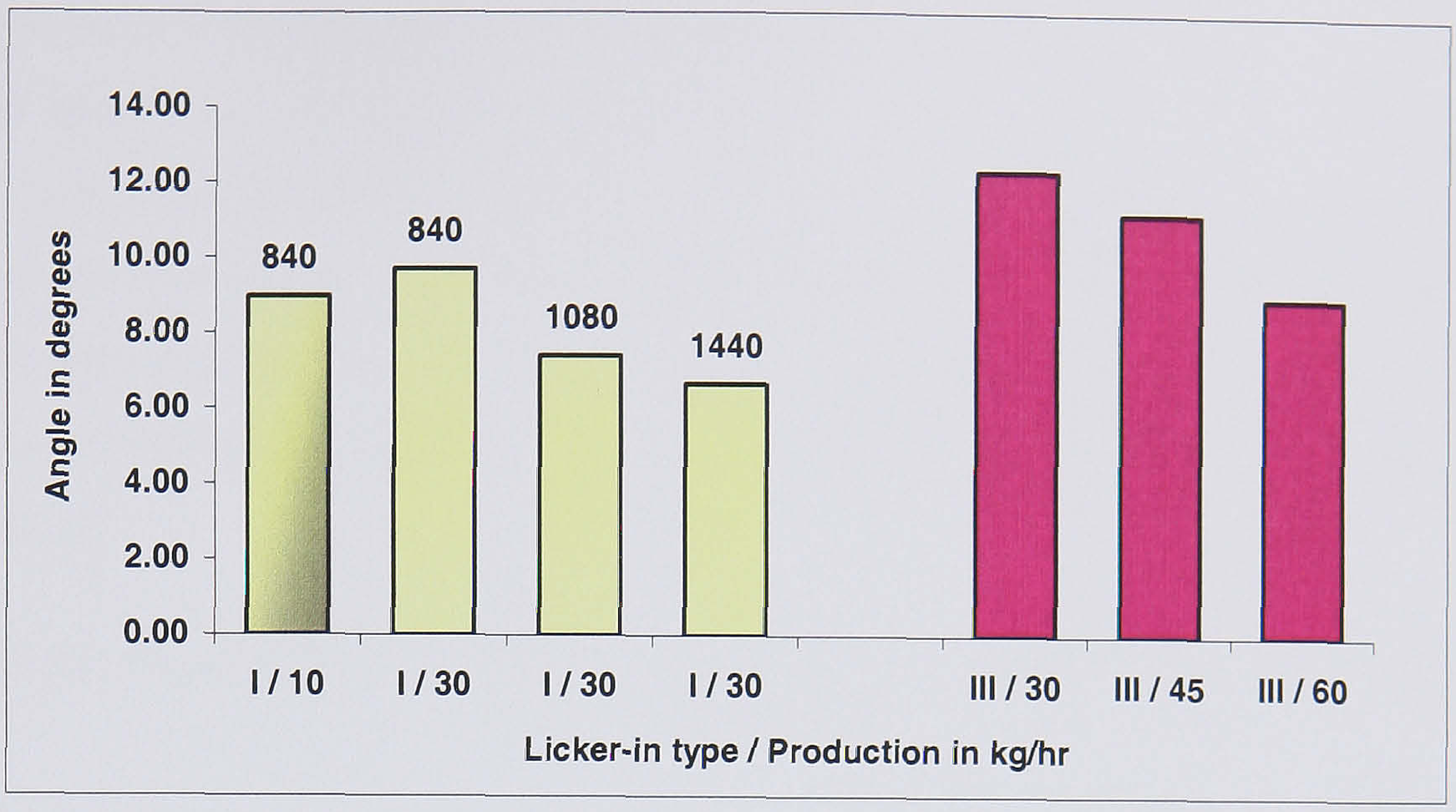


Figure 5.20 – Fibre orientation with single and triple licker-in arrangements for NHH 44

Like DCH 32 cotton, the fibre orientation improved as the licker-in speed was increased from 840 rpm to 1440 rpm and as with DCH 32, there was a small deterioration in orientation when the production was increased from 10 to 30 kg per hour at 840 rpm. Similarly, with DCH 32 cotton, the fibre orientation improved as the production rate was increased with the triple licker-in.

Figure 5.21 shows the FER with single and triple licker-in arrangements for DCH 32 cotton.

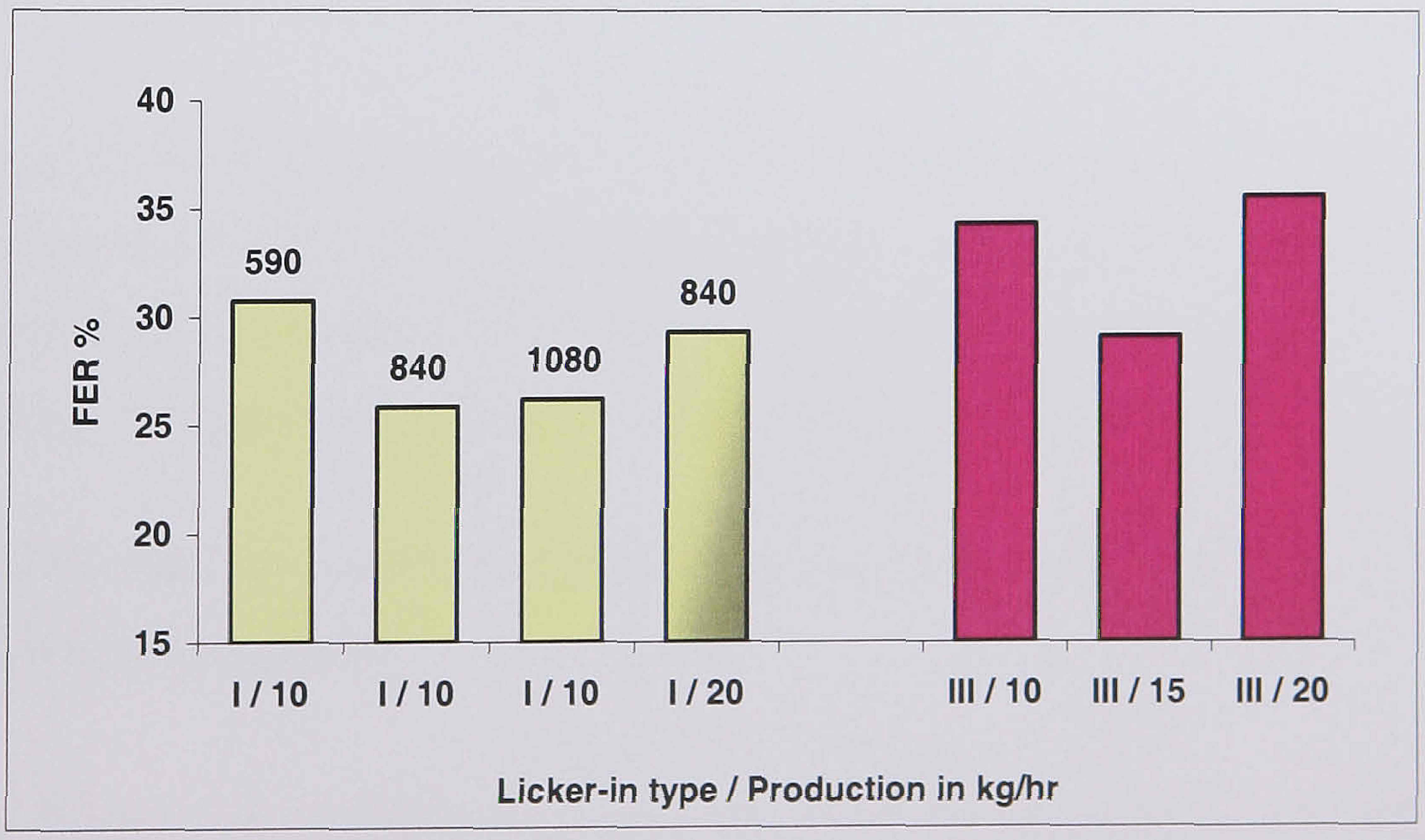


Figure 5.21 – FER with single and triple Licker-in for DCH 32 cotton

It can be seen from Figure 5.21 that the FER decreases initially when the single licker-in speed was increased from 590 rpm to 840 rpm and does not change with further increases in speed. As the production rate was increased from 10 to 20 kg per hour for the single licker-in, the FER also increased. The triple licker-in does not show any particular trend with changes in production rate, but the FER values are greater than for the single licker-in at the same production rates of 10 and 20 kg per hour.

Figure 5.22 shows the FER with single and triple licker-in systems for NHH 44 cotton.

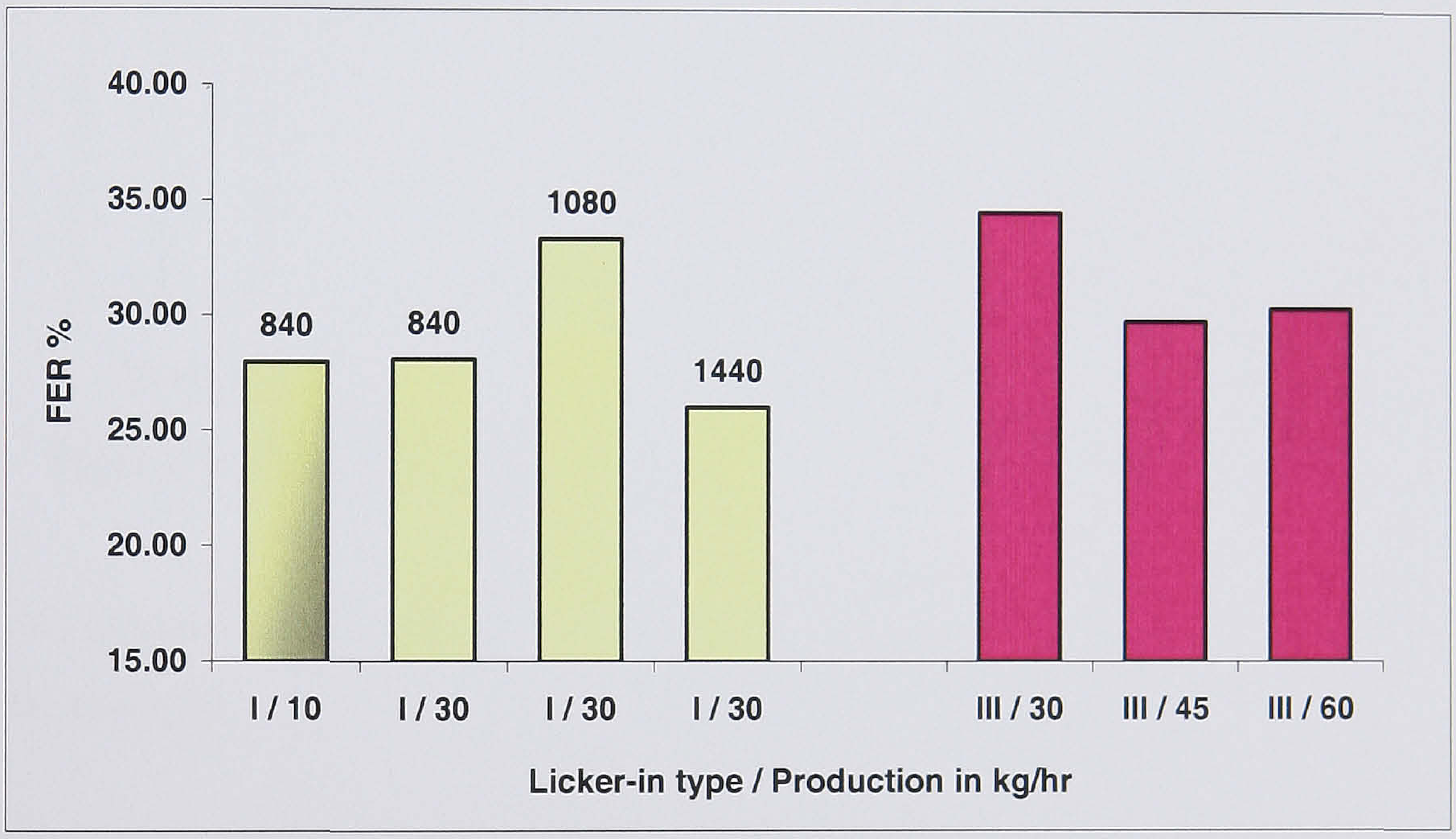


Figure 5.22 – FER with single and triple licker-in for NHH 44 cotton

From Fig 5.22, with a single licker-in at the different speeds and production rates studied, a trend for the FER is not apparent. The triple licker-in showed a decrease in FER when the production rate was increased from 30 to 45 kg per hour and beyond 45 kg no significant change was noticed.

To shed more light on the fibre configurations on the licker-in surfaces, fibres were classified into three groups

Group 1 – Fibres with a FER less than 20% and orientation less than 20 degrees in the machine direction (reasonably taut fibres).

Group 2 – Fibres with a FER greater than 20% and/or orientation greater than 20 degrees in the machine direction.

Group 3 – Fibres that do not have identifiable orientation or having 'L' or 'U' or any other shapes and in general exhibiting a high degree of FER.

Examples of Group I, II and III fibres are shown in Figure 5.23. The fibre configurations (images) with all experiments are given in Appendices 33 to 45.

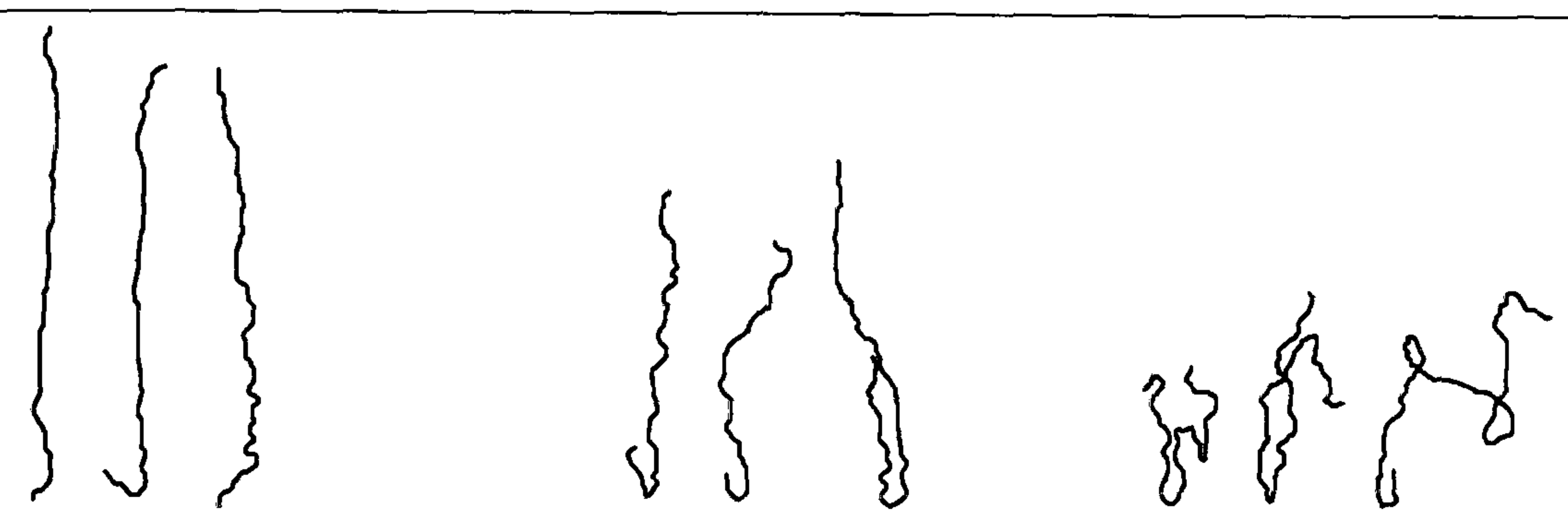


Figure 5.23 – Typical fibre configurations in the groups I, II and III

Table 5.6 gives the distribution of fibres that fall into various groups for the two licker-in systems.

Table 5.6 – Fibre groups with the two licker-in arrangements

Cotton	Licker-in type	Production in kg /hr	Group I	Group II	Group III	Total sample size
DCH 32	SL - 840 rpm	10	19	29	2	50
	TL	10	7	29	14	50
NHH 44	SL - 840 rpm	30	18	24	8	50
	TL	30	10	28	12	50

It can be seen that at the same production rates, the single and triple licker-in arrangements show significantly different distribution patterns, especially of the

Group I and III fibres. Triple licker-in has fewer fibres in Group I compared to single licker-in, but has more fibres in Group III. This suggests that fibres are distorted on the licker-in surfaces of the triple licker-in arrangement. With single licker-in, there was an increase in Group I fibres (and a reduction in Group II fibres) with an increase in licker-in speed for DCH 32 cotton and there was a decrease in Group I fibres with an increase in licker-in speed (and an increase in Group II fibres) for NHH 44 cotton (see Appendix 32). The medium staple and medium fine NHH fibres (relatively higher stiffness) may not be as well anchored to the licker-in clothing as the long and fine DCH 32 fibres possibly are (low flexural rigidity or stiffness). Also at higher licker-in speeds when the fibres tend to move away from the clothing, there is reduced fibre control and resulting in some disorientation of fibres in the process.

Another remarkable aspect emerged when the fibres were grouped according to the length and when the orientations and FER were compared for the single and triple licker-in arrangements. Fibres were grouped into those that are longer than 20 mm and those that are shorter than 20 mm. The results of this analysis for the main experiments are given in Table 5.7.

Table 5.7 – Fibre orientation and crimp ratio with single and triple licker-in

Cotton	Licker-in type	Licker-in speed	Production in kg/hr	Orientation (Degrees)		FER %	
				< 20 mm	> 20 mm	< 20 mm	> 20 mm
DCH 32	SL	840 rpm	10	6.6	4.7	19.4	27.2
	TL		10	17.0	16.6	23.9	36.0
NHH 44	SL	840 rpm	30	5.5	10.8	18.0	31.2
	TL		30	12.4	12.3	23.2	35.2

It is clear from the above table that fibres longer than 20 mm had poor orientation for NHH 44 cotton compared to the shorter ones with the single licker-in, whereas with DCH cotton, the orientation is better for the longer group of fibres. The orientation of both group fibres was similar with the triple licker-in for both cotton varieties. In general, as far as the FER was concerned, the longer fibres showed higher values of FER. Fibres on the triple licker-in showed greater FER than that on single licker-in for both fibre length groups.

The same image analysis was also done for other single and triple licker-in experiments. But because of a sample size of 25 fibres, in some of the experiments, fibres under 20 mm were too few to make a meaningful comparison. Therefore, comparison has been made for those fibres that are longer than 20 mm and the results are shown in Figures 5.24, 5.25, 5.26 and 5.27.

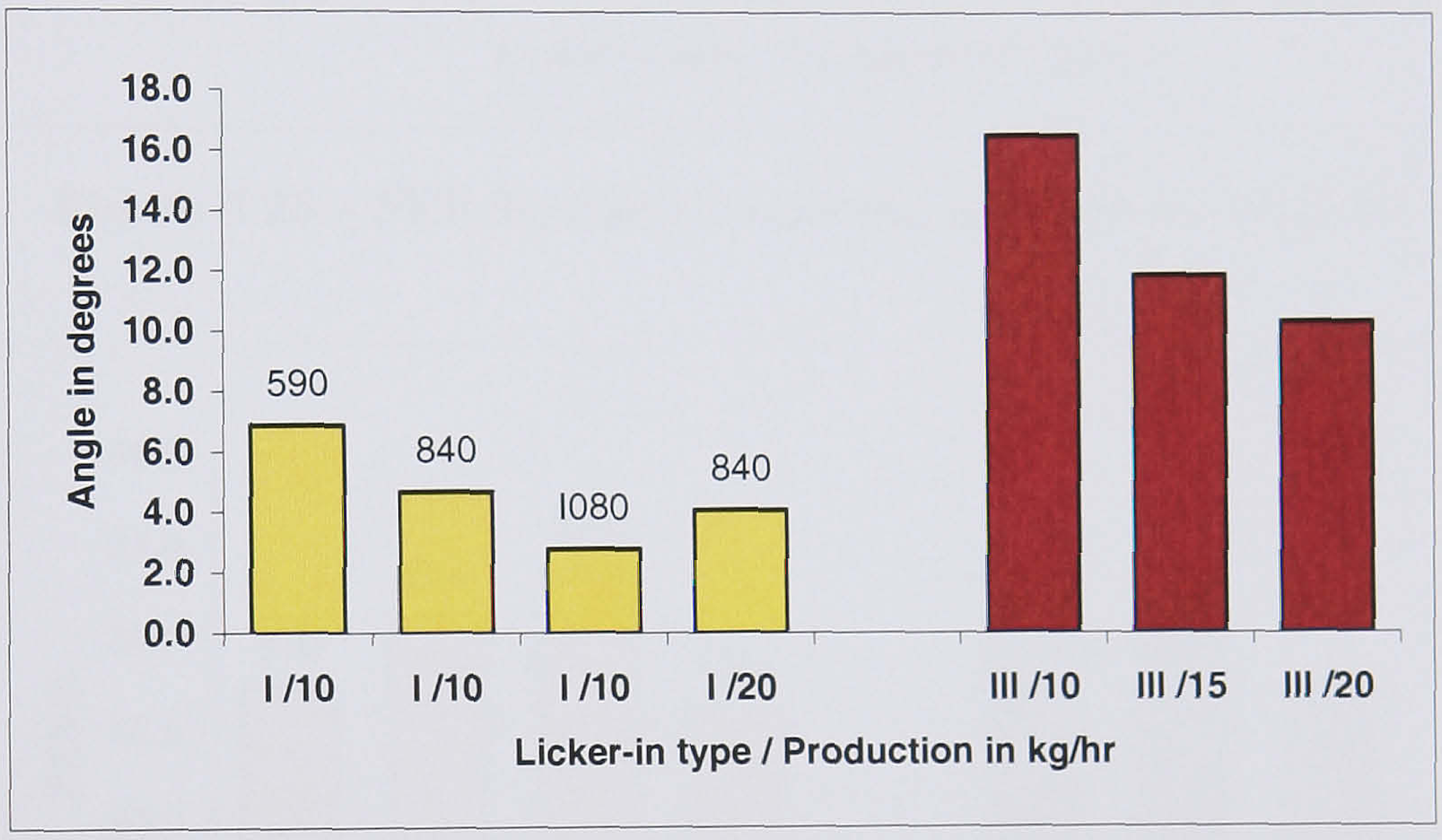


Figure 5.24 – Fibre Orientation for fibres longer than 20 mm for DCH 32

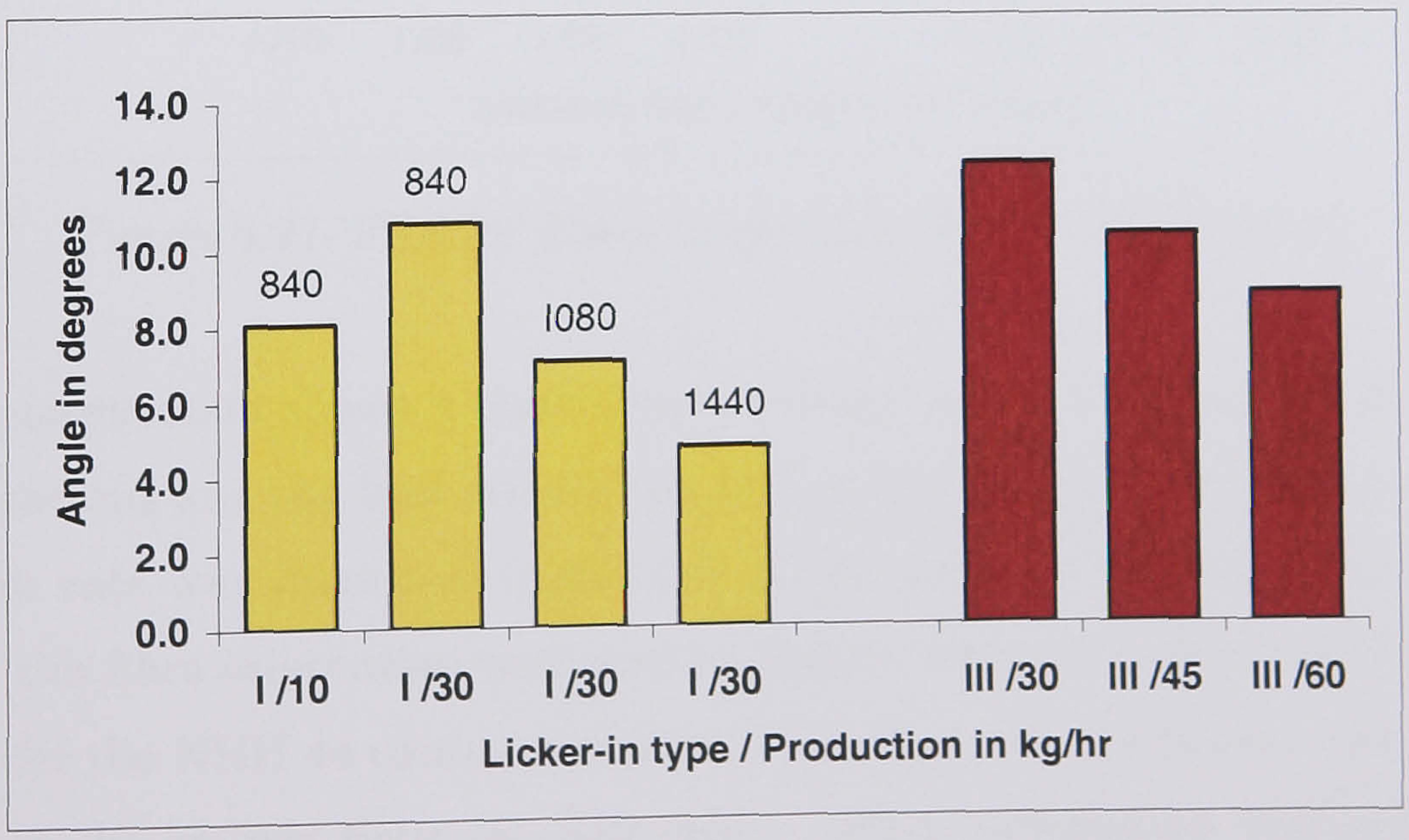


Figure 5.25 - Fibre Orientation for fibres longer than 20 mm for NHH 44

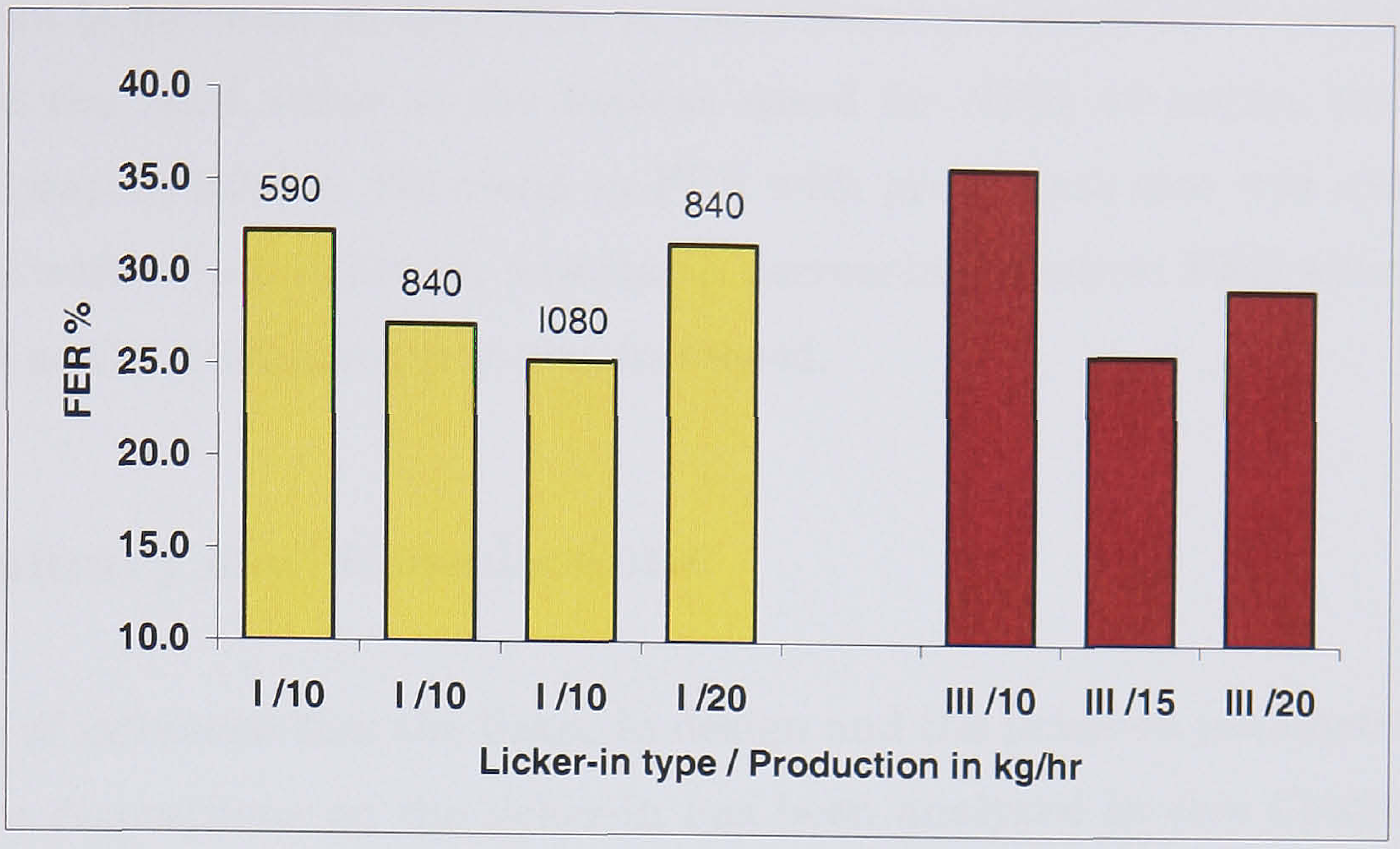


Figure 5.26 – FER for fibres longer than 20 mm for DCH 32

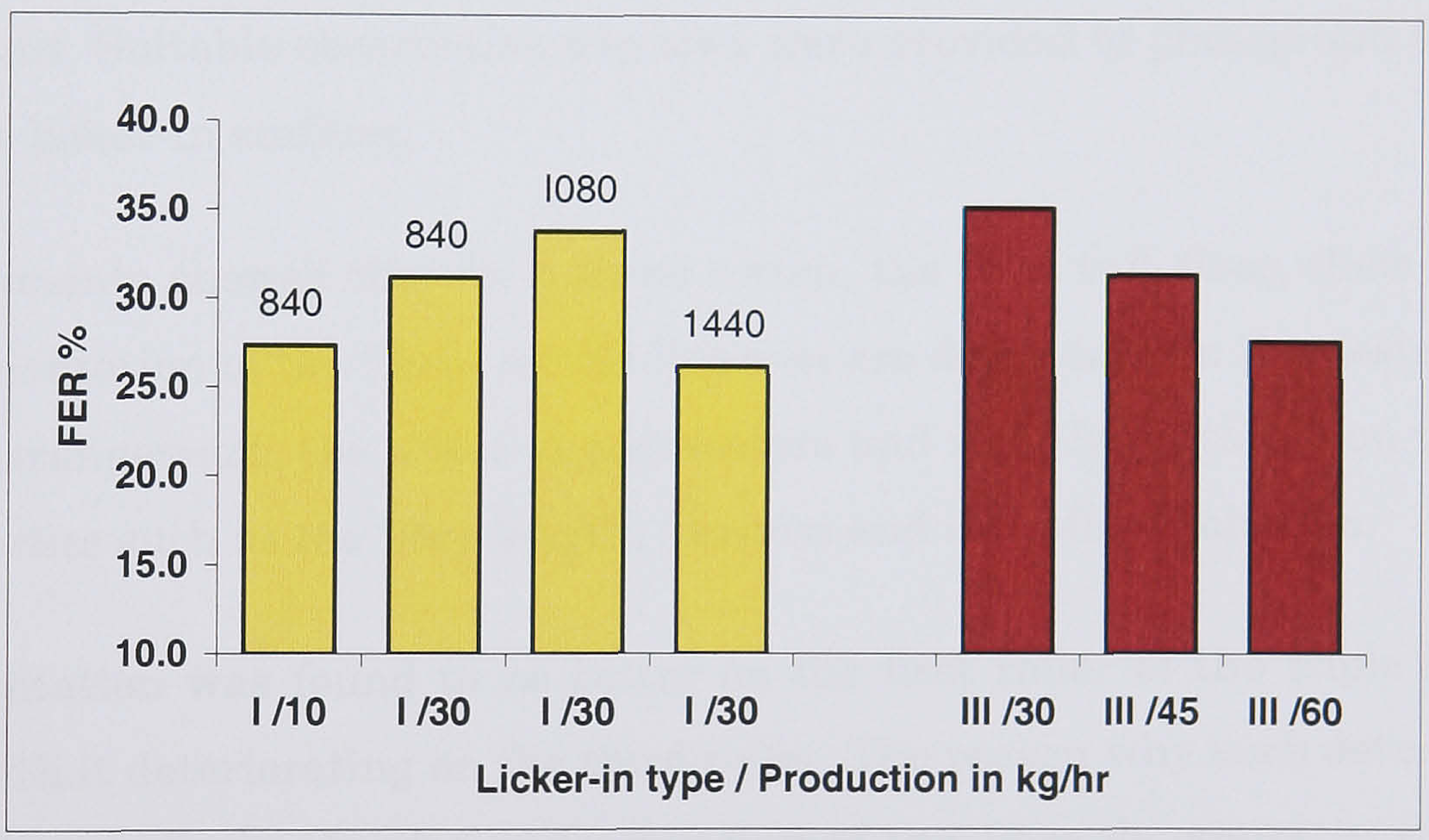


Figure 5.27- FER for fibres longer than 20 mm for NHH 44

The fibre orientation shows a clear trend with the single licker-in for DCH 32 and NHH 44 cottons and the best orientation was at the highest licker-in speed. As the production rate was increased from 10 to 20 kg per hour (at 840 rpm) for single licker-in, the fibre orientation was seen to slightly improve for the DCH 32 cotton; where as for the NHH 44 cotton, it deteriorated when the production was increased from 10 to 30 kg per hour (at 840 rpm). Fibre orientation improved as the production rate was increased for both DCH 32 and NHH cotton varieties with triple licker-in.

FER is shown to decrease as the licker-in speed increased for DCH 32 cotton and it also showed the least value at the highest speed for NHH 44 cotton, though no clear trend was noticeable. No trend in FER with production rate was noticeable for DCH 32 with triple licker-in, whereas a decreasing trend in FER was noticed for NHH 44 as the production rate was increased.

5.4 Summary and Conclusions

The degree of influence that the licker-in design and the licker-in parameters have on the fibre dispositions on the licker-in has been analysed in this Chapter. The single licker-in experiments were conducted on a Crosrol Mark IV high-production card and the triple licker-in experiments were conducted on a standalone triple licker-in unit. Suitable observation windows were provided to photograph the fibre flow on the licker-in surfaces.

The experiments showed that for a given cotton, the fibre tuft sizes, their number and the orientation of the fibres on the licker-in are dependent on the design of the licker-in arrangement, the licker-in parameters and most importantly on the fibre characteristics such as the fibre length, fineness and inter-fibre cohesion.

Fibre orientation was found to be better on the first roller of the triple licker-in system, with it deteriorating on the third roller. The reason why such deterioration takes place requires a careful understanding of the fibre dynamics in the triple licker-in roller arrangement. There are two possible reasons. Firstly, the drafts among the licker-in rollers are quite small, especially between the second and third licker-in rollers (which is about 1.3) that could result in fibre recycling on the second roller (observed with the finer cotton), due to an insufficient transfer coefficient among the licker-in rollers. The fibre transfer between the second and third rollers is dependent on the ability of the third roller to strip away the fibres and for this reason the third roller has more points per square inch than the second roller (about 28% more) and runs at about 30% higher speed than the second roller. However, this was found to be insufficient for the fine and long DCH 32 fibre as lots of fibres recycled on the second roller. This recycling can cause some deterioration in fibre orientation and arrangement. The second reason for the deterioration of fibre orientation could be the increased amount of surfaces that a fibre contacts during its travel at the under and over casings, stationary flats, and which is further compounded by the centrifugal forces that push the fibres away from the clothing. Obviously, if a fibre was not held firmly enough by the clothing, it could easily get disoriented.

The deterioration in orientation of the fibres fed to the main cylinder could hamper the actual carding process. The deterioration was greater in the case of fine DCH 32 fibres; the fibre and yarn quality results also showed deterioration (aided possibly by an increase in the number of tufts with triple licker-in). In the case of the NHH 44 cotton, the difference in orientation of fibres between single and triple licker-in systems was found to be small because the fibres on single licker-in itself had a greater orientation angle in the machine direction; which was possibly due to the higher throughput rate through the licker-in that reduced the degree of combing at the feed roller nip. The quality of the triple licker-in yarn was also better in this case possibly because the improved opening in the licker-in region favoured the triple licker-in to achieve better carding performance and thus to produce better yarns.

The overall results indicate that improvement in the degree of opening in the licker-in zone (with single or triple licker-in) is a factor significantly influenced by the fibre characteristics. In a triple licker-in system, the speed of the first roller was always less and hence the opening at the feed roller /feed plate nip is considerably reduced. In spite of decreased opening at the feed roller nip, short and coarse cotton could be opened easily at the stationary flats of the triple licker-in (due to low fibre cohesion) even at higher throughput rates. However, long and fine cotton usually have a higher degree of fibre cohesion and hence will not open up at the stationary flat so easily; this was observed in this study. The tufts tend to get elongated, but not be broken into smaller tufts. In the case of shorter cotton, such elongated tufts were not noticed even at production rates higher than that used for the fine cotton. In such a situation, a better opening of the tufts at the feed nip can only yield a better carding result; which was not possible with triple licker-in due to low first roller speeds. This reduces the applicability of triple licker-in systems to such cotton varieties that are easily openable like the shorter or coarser varieties of cotton even though the triple licker-in treats the fibre more gently than a single licker-in. In the same breath, it also restricts the throughput in the case of the single licker-in arrangement.

Studies using high-speed photography have thus yielded some vital clues in the understanding of the pre-opening process at the licker-in zone. Chapter 6 will summarise and analyse the findings of all the three phases of this investigation in order to link the findings from the high-speed photography investigation to the carding performance.

Chapter 6

Summary and Discussion of Results

6.1 General Summary

Over the last 50 years, carding production rates have increased significantly. In the 1950s, production was a mere 4 kg per hour compared to current production rates of over 100 kg per hour. Improvements in production are due to a number of developments, namely in card clothing, precision engineering and the development of the triple licker-in design. The introduction of the triple licker-in design such as that by manufacturers like Rieter and Truetzschler has demonstrated that an improved opening in the licker-in zone can increase the card productivity appreciably, especially with shorter or coarser cotton varieties. Despite this, anecdotal evidence from industry has suggested that not all cotton varieties can be processed with the same ease on cards with triple licker-in. Even in cases where the triple licker-in has been successful, there have been indications that fibres processed through a triple licker-in show a greater fibre disorder in the yarns as well as in the fabrics giving them an increased pilling tendency [46].

In spite of the substantial developments in the carding process over the years, a need is felt in the cotton spinning industry for machines that can process all types of cotton with equal ease from the superfine to the longer cotton varieties. Further increases in productivity require a careful study of the existing technology and those factors that are critical to quality and productivity are identified and new designs can be developed accordingly.

The pre-opening section of the carding machine has long been recognised as contributing significantly to the quality of the carding output. The literature review showed that the parameters of the licker-in zone of a single licker-in card have to be optimised to achieve efficient opening at the feed roller nip so that the fibres fed to the main carding cylinder are well opened, well aligned and have a minimum number of tufts. To achieve an optimum opening at the licker-in zone, it is important to choose the right combination of licker-in speed and licker-in zone settings especially those of the feed roller to feed plate. Nevertheless, the single licker-in arrangement has been found to be wanting at high production rates to produce good quality results, because of the limitations posed in increasing the licker-in speed (due to possible fibre damages) [3].

Attempts have been made in the past [46, 64, 65, 67, 72-74, 96] to look at the card output in terms of fibre quality or fibre configuration to comprehend the carding process so that it becomes possible to bridge the gap that exists in our understanding of the carding process. Such studies have brought about a greater understanding of the carding process. However, there is always an element of doubt in the theories based on experimental results that study only the output of a process. Nothing can bring about an equivalent understanding as looking at the process while it is happening. It is not easy to do this without disturbing the process, especially in carding where the machine settings are very close. In the past, research has been successfully carried out on the carding machine using high-speed photography at the University of Leeds [40].

For this work, it was decided to investigate the pre-opening performances of the single and commercial triple licker-in systems in use today. This work is needed to enhance the understanding of the fibre dynamics within the licker-in zone of the two licker-in systems and its influence on the fibre, yarn and fabric quality. In order to study the differences between the two licker-in systems, it was decided to first look at the quality of the yarns spun using the two licker-in systems and at the fibre configurations within those yarns, followed by a study of fibre and tuft dispositions on the licker-in surfaces (by using high-speed photography).

This investigation was accordingly divided into 3 phases.

- Phase I investigated the fibre, yarn and fabric qualities with single and triple licker-in systems,

- Phase II investigated the fibre arrangements in yarns spun using the single and triple licker-in systems, and

- Phase III investigated the fibre opening process within the two licker-in systems using high-speed photography.

6.1.1 Phase I findings

Two cotton varieties (NHH 44 and DCH 32) that differed widely in their characteristics were used for the study. One was a long staple, fine cotton and the other was a medium staple, medium fine cotton. The study was a controlled one, i.e. each cotton was perfectly blended and processed through the same set of machines, spindles etc., from blow-room to spinning. All investigations were carried out on a high-speed Crosrol Mark V carding machine in a production environment. For the study, the single licker-in of the Mark V card was replaced with a specially fabricated triple licker-in unit resembling the commercial DK 803 triple licker-in.

Phase I investigations concluded that the single licker-in speed and licker-in design influenced the fibre, yarn and fabric quality significantly. The single licker-in showed better sliver and yarn quality results than the triple licker-in when processing the long, fine cotton. At optimum speed (840 rpm), the single licker-in produced a yarn that was 25% better in terms of imperfections than the triple licker-in at the same production rate (10 kg per hour). However, when it came to processing medium staple, medium fine cotton, the triple licker-in fared better than the single licker-in at the same production rate (30 kg per hour), producing a yarn that had about 20% fewer imperfections and better knitted fabric appearance. However, the knitted fabric pilling tendency was found to be higher with the triple licker-in for the medium staple, medium fine cotton.

It was also observed that the hairiness of the yarns was influenced by the licker-in parameters/ design. A clear reduction in yarn hairiness was seen with a decrease in single licker-in speed for both cotton varieties. At the same production rates, the triple licker-in processed material showed 10-20% higher hairiness values than that of the single licker-in processed material (at the optimum licker-in speed of 840 rpm) for both cotton varieties.

6.1.2 Phase II findings

Phase II investigations determined the influence of the licker-in design on the fibre configuration in the yarns spun during Phase I investigations. The yarns contained 0.05% of black fibres in their structure and the tracer configurations were studied using a microscope under a magnification of 100 times.

Phase II investigations established that the single licker-in speed and the licker-in design did indeed influence the fibre arrangement in yarns. It was established that the number of fibre hooks differed with the type of licker-in arrangement. With triple licker-in, for the long, fine cotton, the trailing hooks were greater (about 40%) compared to the single licker-in, whereas for the medium staple, medium fine cotton, trailing hooks were only half that seen with the single licker-in at the same production rate and at the optimum speed of 840 rpm of single licker-in. It was also found that other irregularities in the fibre paths such as kinks, loops, double fibres (twins) etc. differed among the yarns produced with the two licker-in arrangements. In the yarns spun from the medium staple cotton, the numbers of kinks, fibre twins, and fibre hairs projecting out of the yarn were greater (about 30%) with the triple licker-in.

It was observed that the Fibre Extent Ratio (FER, page 139) of shorter fibres was greater than that of the longer fibres. It was also observed that the FER values of the longer group of fibres (> 25 mm) were significantly influenced by the licker-in arrangement. For both the cotton varieties used in the study, the triple licker-in showed higher FER values (for fibres > 25 mm) than the single licker-in. Also, the

FER value increased when the single licker-in speed was increased. A remarkable aspect regarding the fibre disorder in the yarn is that the disorder present in the yarn is there in spite of it undergoing a huge amount of draft during its manufacture. This implies that the fibre disorder in card sliver must be substantially higher than in yarn and whatever is seen in the yarn is only residual disorder.

6.1.3 Phase III findings

The degree of influence that the licker-in design and the licker-in parameters have on the fibre dispositions on the licker-in surfaces was investigated in the third phase of the investigations using high-speed video photography. All the single licker-in experiments were conducted on a Crosrol Mark IV high-production card in the carding laboratory at the University of Leeds and the triple licker-in experiments were conducted on a triple licker-in unit that was used for Phase I investigations. Suitable observation windows were provided on the licker-in undercasings of the single and triple licker-in arrangements so that photographs of the fibre flow on the licker-in surfaces could be taken.

Phase III investigations showed that orientation of the fibres on the licker-in surfaces (in the machine direction) of the single and triple licker-in arrangements were significantly different from one another. The triple licker-in showed inferior orientation compared to the single licker-in with both varieties of cotton. The difference between the orientation angles was greater (about 12 degrees) with the long and fine cotton and smaller (2.7 degrees) with the medium staple cotton. Fibre orientation was observed to be better on the first roller of the triple licker-in system and it deteriorated on the third roller. The fibres on the triple licker-in also showed greater FER values (20-30% more) than those on the single licker-in. It was also observed that the number and size of tufts on the licker-in surface, which indicate the degree of opening, were different between the two licker-in designs. While the single licker-in showed fewer tufts longer than 9 mm for the long and fine cotton, the triple licker-in showed fewer tufts longer than 9 mm with medium staple, medium fine cotton. In general, it was observed that fibre flow on the single and triple licker-in surfaces was not uniform but discontinuous with groups of fibres or tufts appearing at irregular intervals. A large number of fibres were also found to recycle on the second licker-in in the case of the long and fine cotton.

6.2 Pre-opening and its influence on carding performance

The following discussion details how the pre-opening process influences the fibre and yarn quality results, and also the fibre configurations in yarns.

This discussion is structured as follows:

1. Degree of opening in the licker-in zone vs. quality results.
2. Fibre disposition on the licker-in surface vs. fibre arrangement in yarns.

6.2.1 Degree of opening in the licker-in zone vs. quality results

As discussed earlier, in terms of quality results, the triple licker-in performed well with the medium staple, medium fine NHH 44 cotton and single licker-in performed well with the long, fine DCH 32 cotton. Interestingly, when processing NHH 44, at a production rate of 30 kg per hour, in spite of higher nep content (10% more) in the fibres collected from the triple licker-in than single licker-in (at the optimum speed of 840 rpm), nep content in the sliver was observed to be 30% less than that of the single licker-in (observations during Phase I). The yarn quality with the triple licker-in was also superior in terms of thick places, neps and Classimat faults with NHH 44 cotton. The fabric appearance in terms of regularity and cleanliness was also better than that of the single licker-in. The reason for this was identified when the licker-in surfaces were studied using high-speed photography. It was observed that the number of tufts (of all sizes) on the licker-in surface was significantly less with the triple licker-in when processing the NHH 44 cotton. This leads to the conclusion that for the NHH 44 cotton, the carding process between the cylinder and flats was superior due to better opening in the licker-in zone with the triple licker-in.

When processing DCH 32 cotton, at a same production rate of 10 kg per hour, it was observed that the neps were about 20% less and the fibre mean length better of the fibres collected from the triple licker-in than the single licker-in (at the optimum speed of 840 rpm). However, the card sliver showed 8% more neps and also a slightly lower mean length (and higher short fibre content) with the triple licker-in compared to the single licker-in. The yarn quality was also inferior to the single licker-in in terms of thin, thick, neps and also Classimat faults. The reason behind this was also revealed when the licker-in surfaces were studied using high-speed photography. The number of tufts (>3 mm) on the triple licker-in was significantly higher than the single licker-in. This leads to the same conclusion, as with NHH 44 cotton, that the carding process improves if the number of tufts in the material fed to the cylinder is less. As the single licker-in showed better opening than the triple licker-in in case of the fine cotton, the sliver and yarn quality was found to be superior.

These findings confirm that the degree of opening in the licker-in zone is critical in determining the output quality of the carding machine.

6.2.2 Fibre disposition on the licker-in surface vs. fibre arrangement in yarns

Looking at the fibre, yarn and fabric quality results, the only reasons that could suggest that the licker-in has a certain degree of influence on the fibre configuration in yarns is the changes in yarn hairiness and fabric pilling tendency (at least with one of the two cottons in the experiments). However, study of the tracer fibre configurations confirmed that licker-in design has considerable influence on fibre configurations in the yarn. With such high mechanical drafts between the carding machine and the spinning process, the changes noticed are only residual in nature and clearly, the changes in card sliver could be expected to be profound.

When the single licker-in speed was increased, it was observed that orientation of the free fibres on the licker-in improved and the FER values decreased. At the same time, the FER values of the fibres in the yarn increased with an increase in licker-in speed. There are two probable reasons. Firstly, as the licker-in speed was increased, though the orientation of free fibres improved, a number of well-opened clusters were seen to increase as well and within these fibre clusters, the orientation of fibres was poor. A high degree of opening at the licker-in stage without proper orientation of all the opened fibres could be a reason for higher FER values in yarn. Alternatively, it could be that the surface speed ratio between licker-in and cylinder drops as the licker-in speed is increased. This could mean that the stripping action by the cylinder, which also involves some kind of combing action, diminished resulting in a decreased fibre orientation on the main cylinder. Previous research work also showed that the orientation of fibres deteriorated on the cylinder when the licker-in speed was increased [42].

As discussed earlier, the fibres on the triple licker-in surface (third licker-in roller from the feed end) had inferior orientation and higher values of fibre extent ratio (FER) when processing both varieties of cotton compared with the single licker-in at the same production rate. In fact, the fibres in yarns produced from the triple licker-in card exhibited higher FER values than the single licker-in processed material with both varieties of cotton. By linking this inferior fibre orientation and higher FER values on the triple licker-in surface with the higher FER values in yarn, the picture becomes complete. This shows that if the fibres are disordered on the licker-in surface, even with the combing action between the cylinder and flats, the fibres will continue to retain some of the disorder (found on the licker-in) when the fibres are transferred from the cylinder to the doffer.

Another important observation made during Phase III of the investigation was the high amount of fibre recycling taking place on the second licker-in of the triple licker-in system, especially with the fine and long cotton. Although the exact nature of its implications is not clear, the recycling of fibres probably affected the fibre orientation on the licker-in and thus the carding process and the fibre configurations in the card sliver.

6.3 Fibre opening in the licker-in zone – Some Considerations

From the investigations conducted with the single and triple licker-in systems, it has become clear that the fibre opening in the licker-in zone is a complex phenomenon and several factors play a part in determining the quality of the pre-opening and thus the quality of the carding output. The following are the key factors, which emerged during this investigation that could determine the quality of the pre-opening.

1. Fibre characteristics such as length, fineness and most importantly inter-fibre cohesion.
2. The degree of opening at the feed roller-feed plate nip by the licker-in.
3. Licker-in type: Single or Triple
4. The degree of opening at the stationary flats of a triple licker-in system.
5. The production rate of the carding machine.
6. The speed/s of the licker-in rollers

The following discussion will now consider the fibre processing in the licker-in zone based on the findings of this investigation.

6.3.1 Fibre opening vs. Fibre Cohesion

The most important factor that determines the fibre processing in the licker-in zone is the inter-fibre cohesion. The higher the cohesive force, the more difficult it is to open the fibre at the feed plate-feed roller nip or at the stationary flats in the licker-in zone. When processing a cohesive raw material, the speed of the licker-in must be optimal and preferably lower, especially if the raw material is longer and finer. A cohesive fibre tuft resists the opening by the licker-in teeth more and so using lower licker-in speeds can reduce fibre damage. With a cohesive material, lower licker-in speeds would also reduce the fibre tufts being pulled out of the feed roller nip (discussed in Chapter 5, Section 5.3.1.1b). The feeding rate must be reduced so that the fibre tufts come into contact with the licker-in for a longer duration as more teeth must comb through every square inch of the feed material.

When processing a not so cohesive raw material, depending on fibre characteristics such as length, strength and fineness, it is possible to increase the licker-in speeds to such a level that it does not break the fibres or trash particles present in the material; while ensuring that sufficient surface speed ratio between licker-in and the cylinder is maintained. At high production rates, because the combing is decreased at the feed roller nip, more large size tufts will be produced and also the orientation of the fibres fed to the cylinder will be poor. The carding action between the cylinder and the flats will also be affected if more tufts are present in the material fed to the cylinder. Therefore when processing a less cohesive cotton, it is possible to use a triple licker-in to break down the tufts to smaller ones (because of the stationary flats used in triple licker-in system) and thus permit an increase in the throughput rate of the card.

6.3.2 Triple licker-in vs. Fibre Orientation

It is apparent that because of the way the triple licker-in arrangement opens the tufts (using the stationary flats), the fibre orientation and order of the material delivered to the main cylinder is poorer i.e. the fibres are more disoriented and disordered and this affects the carding process and also the fibre configurations in slivers. The reason why this is taking place will be discussed in the following section.

The speed of the first licker-in in a triple licker-in system is low because of the minimum speed ratios required among the rollers, and between the third licker-in roller and the cylinder, to ensure fibre transfer. Typically the surface speed of the first roller is only one-fourth of the cylinder surface speed compared to about one-half for a single licker-in system. Though this is advantageous in processing weaker or longer cotton, as the opening at the first roller will be gentle, it would reduce the opening at the feed roller-feed plate nip. Reduced opening (combing) does not just mean an increase in the number of tufts, but also a reduced orientation of the fibres on the licker-in. The drafts (surface speed ratios) between the rollers in the triple licker-in system are also small (about 1.5 between the first and second rollers and about 1.3 between second and third rollers), as use of higher drafts among the rollers will further decrease the first roller speed. At low surface speed ratios among the rollers, the orientation may not improve during transfer; rather it may even deteriorate. Owing to the smaller dimensions of the licker-in rollers, the arc of contact is very small and the fibre transfer has to take place closer to the transfer point. It is possible that during such transfer, fibres are not properly stripped and the stripping does not involve any combing action and thus may increase the disorder.

Also in a three licker-in system, the length travelled by a fibre in the licker-in zone typically increases by a factor of two (compared to a 254 mm diameter single licker-in). This will mean an increased number of contact points. Because smaller licker-in rollers are used in a triple licker-in system, the centrifugal forces are greater and this means that most of the fibres would travel closer to the periphery of the rollers and those fibres that are not properly held by the wire points will disorientate at points of surface contact.

It is clear from the findings that the design of licker-in zone plays a critical role in determining the effectiveness of the carding process. An efficient design of the licker-in zone will go a long way in achieving a good carding quality at high-productivity. Chapter 7 concludes the findings of this investigation and also discusses the scope for future work in the study of the licker-in zone.

Chapter 7

Conclusions and Suggestions for future work

7.1 Conclusions

This investigation conducted in three phases has come to the following conclusions.

1. The licker-in design has a significant influence on the carding performance in terms of sliver, yarn and fabric quality. Licker-in and production parameters need to be optimised to achieve an optimal carding performance. In general, to achieve a good carding performance the fibres fed to the carding cylinder must be well opened and well aligned with a minimum number of tufts.

2. The opening action at the licker-in zone is a complex process involving several factors. The characteristics of the raw material such as fibre length, fineness and cohesive properties play a significant role in determining the type of opening action that is suited for the given raw material.

3. Single licker-in limits carding productivity because of the limitations imposed by the degree of pre-opening required in the licker-in zone to produce optimum quality results. Limitations are primarily due to the need to avoid fibre damage at increasing licker-in speed.

4. A cohesive material requires more action by the licker-in at the feed roller-feed plate nip to achieve the necessary opening required for efficient carding. Higher licker-in speed does not necessarily produce better opening and with cohesive fibres, tufts are pulled out of the feed-roller nip because of the opening forces generated by the licker-in at higher speeds. This means that the rate of feeding at the feed roller has to be small in order to ensure a greater contact time of the fibres with the licker-in. Correspondingly, this

has an effect on the card throughput rate. Lower licker-in speeds were found to be better in reducing the number of tufts when processing cohesive fibres. Therefore, a single licker-in is ideal for finer and longer fibres (with higher cohesion) and the triple licker-in is more useful for processing short to medium staple cotton that have above average fineness.

5. When cohesive material is carded, opening using stationary flats in the triple licker-in arrangement does not seem to be an efficient method of opening. This is probably because the existing stationary flats design used in the licker-in zone has not been optimised to achieve the right degree of opening. Also it is possible that the points per square inch used on stationary flats in the triple licker-in system are insufficient to process a cohesive material and may need to be increased further.

6. Fibre dispositions on the licker-in vary with the type of licker-in and with licker-in parameters such as speed. The fibres on a triple licker-in show more disorder than those on single licker-in at the same production rate.

7. The licker-in design has a significant influence on the fibre configuration in the sliver and eventually in the yarns. Yarns spun from material processed through the single licker-in show less fibre disorder than that of the triple licker-in processed material. The triple licker-in design needs further optimisation to improve the fibre configuration in both the sliver and the yarn.

8. The differences in the ideal throughput rates when carding different cotton varieties show that the mechanical carding process is still in its formative years even after being in existence for 250 years and needs to develop substantially to narrow the gap between the productivity rates achieved for different cotton varieties. Further research is required to understand the pre-opening process, as it has got a remarkable potential to increase the carding productivity.

7.2 Suggestions for future work

To study all the main variables involved in the licker-in zone of single and triple licker-in systems is a huge task and is beyond the scope of this thesis. But certainly the study has shown some interesting results; which form the basis for further research that would improve the understanding of the pre-opening process even further.

The following are the suggestions for future research work:

1. Fibre configurations in card sliver with single and triple licker-in arrangements require investigation. In this study, it was not possible to study the fibre configurations in both sliver and yarn due to time constraints.

2. It has been a considerable time since anyone researched the fibre configurations in card sliver, especially with modern carding machines running at 40 or 50 kg per hour. A study of fibre configuration in card sliver produced at different production rates seems increasingly important.

3. The influence of different licker-in roller speeds and the influence of different speed ratios among the licker-in rollers of a triple licker-in design on fibre and yarn quality would make an interesting and useful study.

4. Inter roller fibre transfer in the triple licker-in system needs to be studied further with different varieties of cotton.

5. Fibre transfer between the licker-in and the cylinder with a triple licker-in system is another aspect of carding that needs to be investigated.

6. In this investigation, high-speed photography was used to study the fibre flow on the licker-in surface with two cotton varieties. This could be developed further and it could be used to study the pre-opening process with different fibre varieties (natural and man-made) using single and triple licker-in designs.

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APPENDICES

APPENDIX-1

NHH 44 Cotton Fibre Length Test Results (AFIS)

Sample Identification	**M**	**N**	**A**	**B**	**C**	**J**	**K**	**L**
Sample Detail	**Raw cotton**	**Lap cotton**	**Triple Licker-in**	**Triple Licker-in**	**Triple Licker-in**	**Single Licker-in**	**Single Licker-in**	**Single Licker-in**
Speed (rpm)			*	*	*	**1440**	**1080**	**840**
Production in kg / hr			**30**	**45**	**60**	**30**	**30**	**30**
Length (W) mm	24.03	23.43	23.25	23.39	23.48	23.28	23.2	23.4
Length (W) CV%	36.4	36	37.8	36.4	37.6	37.3	36.6	37
Upper Quartile Length mm	29.29	28.69	28.64	28.75	28.72	28.55	28.6	28.88
Short fibre content %(w)	9.3	9.3	9.9	9.2	9.4	9.5	9.5	9.5
Length (n) mm	18.66	18.03	18.05	18.33	18.28	18.18	18.13	18.27
Length(n) CV%	53.7	54.7	53.8	52.6	53.4	53	52.9	53
Short fibre content % (n)	28.3	29.1	28.7	27.4	27.8	27.8	28	27.8
5 % Length mm	33.86	32.94	33.2	33.28	33.23	33.14	32.93	33.33
Fineness (milli-tex)	153	154	159	158	160	158	157	159
Immature fibre content %	7.5	7.5	7.4	7.3	7.3	6.8	7.3	7.1
Maturity ratio (%)	0.87	0.87	0.88	0.88	0.88	0.88	0.88	0.88

* The Triple licker-in speeds (rolls 1, 2, 3) were 982, 1560, 1960 rpm

APPENDIX-2

NHH 44 Cotton – HVI Test Results

Sample Identification	M	N	A	B	C	J	K	L
Sample Detail	Raw cotton	Lap cotton	Triple Licker-in	Triple Licker-in	Triple Licker-in	Single Licker-in	Single Licker-in	Single Licker-in
Speed (rpm)			*	*	*	1440	1080	840
Production in kg/ hr			30	45	60	30	30	30
2.5 % Span Length	28.73	28.09	27.64	27.6	27.99	27.97	27.98	28.11
50% span length	13.8	13.18	13.22	13.17	13.45	13.39	13.39	13.48
Uniformity Ratio	48	46.9	47.8	47.7	48.1	47.9	47.9	47.9
Strength	21.73	21.5	22.85	22.39	22.83	23.75	22.54	22.62
Elongation %	5.9	5.8	5.6	5.6	5.6	5.7	5.8	5.6

NHH 44 Cotton – AFIS Neps and Shirley Trash %

Sample Identification	M	N	A	B	C	J	K	L
Sample Detail	Raw cotton	Lap cotton	Triple Licker-in	Triple Licker-in	Triple Licker-in	Single Licker-in	Single Licker-in	Single Licker-in
Speed (rpm)			*	*	*	1440	1080	840
Production in kg/ hr			30	45	60	30	30	30
Neps per gram	108	217	61	92	85	73	86	80
Trash %	3.64	1.59	0.082	0.11	0.115	0.142	0.145	0.15

* The Triple licker-in speeds (rolls 1, 2, 3) were 982, 1560, 1960 rpm

APPENDIX-3

DCH 32 – AFIS Fibre Length Test Results

Sample Identification	**O**	**P**	**D**	**E**	**F**	**G**	**H**	**I**
Sample Detail	**Raw cotton**	**Lap cotton**	**Triple Licker-in**	**Triple Licker-in**	**Triple Licker-in**	**Single Licker-in**	**Single Licker-in**	**Single Licker-in**
Speed (rpm)			*	*	*	**1060**	**840**	**590**
Production in kg/ hr			**10**	**15**	**20**	**10**	**10**	**10**
Length (W) mm	27.62	28.4	27	27.47	29.67	27.32	27.55	27.16
Length (W) CV%	36.4	37.7	41	40	40.2	39.4	39.4	40.3
Upper Quartile Length mm	34.18	35.6	34.63	34.99	34.55	34.74	34.94	34.55
Short fibre content %(w)	7.1	7.4	9.6	9	9.4	8.5	8.3	9.3
Length (n) mm	20.48	20.49	18.66	19.11	18.89	19.58	19.57	19
Length (n) CV%	58.9	62.2	66.9	66.2	65.5	63	63.9	65.6
Short fibre content % (n)	28	29.9	34.9	34.1	34.1	31.5	31.7	33.9
5 % Length mm	38.82	40.95	39.53	39.92	39.54	39.73	40.1	39.67
Fineness (millitex)	132	121	130	127	129	131	129	127
Immature fibre content %	7.4	8.4	8.4	8.4	8.4	8	8	8.7
Maturity ratio (%)	0.84	0.81	0.83	0.82	0.82	0.83	0.83	0.82

* The Triple licker-in speeds (rolls 1, 2, 3) were 755, 1202, 1516 rpm

APPENDIX-4

DHC 32 – HVI Fibre Length Test Results

Sample Identification	O	P	D	E	F	G	H	I
Sample Detail	Raw cotton	Lap cotton	Triple Licker-in	Triple Licker-in	Triple Licker-in	Single Licker-in	Single Licker-in	Single Licker-in
Speed (rpm)			*	*	*	1060	840	590
Production in kg/ hr			10	15	20	10	10	10
2.5 % Span Length	34.94	35.03	34	34.1	34.03	34.17	34.14	33.94
50% span length	17.13	16.27	16.19	16.17	16.01	16.44	16.02	16.16
Uniformity Ratio	49	46.4	47.6	47.4	47	48.1	46.9	47.6
Strength	26.73	26.8	23.26	23.68	23.04	22.85	23	22.98
Elongation %	7.9	7.5	7.5	7.5	7.3	7.3	7.4	7.4

DCH 32 – AFIS Fibre Neps and Sliver Trash %

Sample Identification	O	P	D	E	F	G	H	I
Sample Detail	Raw cotton	Lap cotton	Triple Licker-in	Triple Licker-in	Triple Licker-in	Single Licker-in	Single Licker-in	Single Licker-in
Speed (rpm)			*	*	*	1060	840	590
Production in kg/ hr			10	15	20	10	10	10
Neps per gram	262	412	120	144	175	104	111	91
Trash %	3.62	2.35	0.087	0.108	0.11	0.046	0.048	0.076

* The Triple licker-in speeds (rolls 1, 2, 3) were 755, 1202, 1516 rpm

APPENDIX-5

Process parameters (General)

Parameter	Ne 20s/ 29.53 tex	Ne 80s/ 7.38 tex
Cotton used	NHH 44	DCH 32
Blow-Room Lap linear density (ktex)	420	350
Card sliver linear density (ktex)	4.91	3.28
Draw-frame		
No of doublings / sliver linear density (ktex)		
Breaker (Cherry)	8/ 5.37	8/ 2.95
Finisher (RSB)	8/ 5.37	8/ 2.95
Bottom roller Settings – Breaker	40/40/43	42/42/45
Break draft-Breaker	1.84	1.74
Bottom roller Settings – Finisher	37/40	42/46
Break draft- Finisher	1.28	1.28
Speed frame		
Roving linear density (Ne / tex)	1.1 / 537	2.0 / 295
Spindle Speed	900	900
Bottom roller setting	44/50/42	44/50/45
Break draft	1.11	1.11
Twist per metre	54.3	61.4
Spinning		
Total draft	18.2	40
Break draft	1.14	1.16
Bottom roller setting	42.8/ 60	42.5/60
Spindle Speed	12,000 rpm	14,000 rpm
Spacer	3.5 mm	2.75 mm
Yarn twist per inch / twist per metre	16.5/ 651	33.1/ 1303
Yarn twist multiplier (Ne)	3.70	3.70

APPENDIX 6

DCH 32: TEST RESULTS OF FIBRE SAMPLES TAKEN FROM LICKER-IN

	Lap	Single Licker-in				Triple Licker-in		
Licker-in speed (rpm)		**590**	**840**	**1080**	**1440**	*	*	*
Production rate in kg/hr		**10**	**10**	**10**	**10**	**10**	**15**	**20**
Upper Quartile Length UQL (w) mm	35.05	34.8	33.8	33.6	32.6	34.5	34.4	34.4
Length L(w)	28	27.4	26.3	26.3	24.5	27.4	27.2	27.2
Length L(n)	20.65	19.5	17.8	17.6	14.1	20	19.5	19.7
Length 5%(n)	40.4	39.9	38.4	38.5	36.5	39.9	39.7	39.6
Short fibre content SFC %	7.2	8.4	10.1	10.3	16	7.8	8.4	8.2
Nep size (microns)	731.5	704	686	706	716	720	728	741
Nep count per gram	546	1348	1406	1358	1247	*1080*	*1089*	*1061*
Seed Coat nep size	1232.5	1364	1049	1134	987	1202	985	1249
Seed Coat Nep count	8	9	10	29	25	9	3	7

* The Triple licker-in speeds (rolls 1, 2, 3) were 755, 1202, 1516 rpm

APPENDIX 7

NHH 44: TEST RESULTS OF FIBRE SAMPLES TAKEN FROM LICKER-IN

	Lap	Single Licker-in				Triple Licker-in			
Licker-in speed (rpm)		**590**	**840**	**1080**	**1440**	*	*	*	*
Production rate in kg/hr		**30**	**30**	**30**	**30**	**10**	**30**	**45**	**60**
Upper Quartile Length UQL (w) mm	28.3	29.4	28.8	29.1	28.9	28.5	28.7	29	28.9
Length L(w)	22.9	24.2	23.2	23.7	23.6	23.3	23.4	23.6	23.6
Length L(n)	18.3	18.9	17.1	18	18.1	17.9	18	18.1	18.7
Length 5%(n)	32.9	34	33.2	33.5	33.4	32.9	32.9	33.5	33.5
Short fibre content SFC %	10.5	8.1	10.7	9.4	9.1	9.7	9.4	9.5	8.8
Nep size (microns)	703	692	695	681	693	691	705	721	697
Nep count per gram	*254*	*341*	*383*	*378*	*375*	*358*	*423*	*471*	*417*
Seed Coat nep size	1111	982	1088	1027	939	1112	1065	1140	1064
Seed Coat Nep count	*20*	7	10	8	16	6	9	7	5

* The Triple licker-in speeds (rolls 1, 2, 3) were 982, 1560, 1960 rpm

APPENDIX 8

YARN QUALITY TEST RESULTS FOR 20S NE / 29.5 TEX YARN

Mixing - NHH 44 (100%)
Spinning tm/tpi - 3.70/16.5
Spinning spindle speed - 12000 rpm

Sample specification	A	B	C	J	K	L
Number of Licker-ins	3	3	3	1	1	1
Licker-in speed (rpm)	982	982	982	1440	1080	840
	1560	1560	1560	-	-	-
	1960	1960	1960	-	-	-
Delivery speed (m/min)	100	150	200	100	100	100
Production (kg/hr)	30	45	60	30	30	30
English count (Ne)	20	20.3	20.1	19.9	20.1	20.3
Strength in pounds	125.8	120.7	121.8	130.3	122.4	123.7
Count strength product (CSP)	2516	2450	2448	2593	2460	2511
Count CV%	1.9	1.2	1	1.1	1.9	1.9
Strength CV%	4.9	2.8	4.3	2.9	4.5	4.2
Evenness Testing with UT3:						
Yarn U%	11.1	11.4	11.6	11.2	11.2	11.3
Uster CV%	14.2	14.6	14.8	14.3	14.4	14.4
Thin (-50%)	1	1	1	1	1	1
Thick (50%)	116	172	197	151	170	138
Neps (+200%)	114	201	236	139	186	134
Total	231	374	434	291	357	273
Thin (-30%)	1306	1473	1566	1294	1296	1361
Thin (-40%)	72	89	96	71	79	77
Thick (+35%)	763	929	1017	843	831	827
Neps (+140%)	583	859	1013	619	707	657
Hairiness tests with UT3						
Hairiness index	6.8	6.2	6.7	6.7	6.6	6.8
Standard deviation (Sh.)	1.7	1.6	1.8	1.9	1.8	1.8
Single yarn strength & elongation:						
Breaking load (gms)	472.3	491.1	469.5	481.4	478	465.2
CV% of BL	8.9	13.9	8.6	8.7	7.1	6.8
Elongation %	5.2	5.1	5	5	4.9	4.7
CV% of elongation	5.8	10.8	7.5	12.1	6.5	5.4
RKM	16	16.6	15.9	16.3	16.2	15.8

APPENDIX 9

YARN CLASSIMAT FAULTS FOR 20s Ne / 29.5 tex YARN

Sample Identification	A	B	C	J	K	L
Number of licker-ins	3	3	3	1	1	1
Licker-in speeds	982	982	982	1440	1080	840
	1560	1560	1560	-	-	-
	1960	1960	1960	-	-	-
Delivery speed m/min	100	150	200	100	100	100
Production in kg/hr	30	45	60	30	30	30
A1	152	231	333	229	663	185
A2	69	84	96	71	261	63
A3	13	28	17	22	45	30
A4	18	24	10	52	17	60
B1	11	7	10	4	21	13
B2	32	8	22	17	59	12
B3	36	20	17	19	44	45
B4	19	13	10	37	12	88
C1	6	8	3	7	1	2
C2	12	1	8	7	9	10
C3	16	7	6	6	8	23
C4	5	5	3	12	6	15
D1	1	3	2	0	0	2
D2	3	3	3	4	0	3
D3	1	0	0	2	2	2
D4	4	2	1	4	2	8
E	11	5	8	11	1	15
F	12	6	5	10	4	10
G	0	0	1	0	0	0
H1	16	8	8	13	9	17
H2	13	1	4	6	5	18
I1	2	0	0	2	0	0
I2	2	1	1	1	1	3
Total faults	454	465	568	536	1170	624

APPENDIX 10

ZWEIGLE YARN HAIRINESS RESULTS FOR 20s Ne / 29.5 tex YARN

Sample Identification	A	B	C	J	K	L
Number of licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds	982	982	982	1440	1080	840
	1560	1560	1560	-	-	-
	1960	1960	1960	-	-	-
Delivery speed m/min	100	150	200	100	100	100
Production in kg/hr	**30**	**45**	**60**	**30**	**30**	**30**
1 mm	15794	15938	13484	15921	15599	14946
2 mm	2243	2285	1931	2366	2380	2062
3 mm	945	961	773	1019	1035	877
4 mm	1020	948	821	1083	1153	935
6 mm	331	287	250	335	328	290
8 mm	100	90	84	108	109	86
10 mm	16	14	16	21	20	14
12 mm	1	1	1	1	2	1
15 mm	0	0	0	0	0	0
18 mm	0	0	0	0	0	0
21 mm	0	0	0	0	0	0
25 mm	0	0	0	0	0	0
Hairs / 100 m (>3mm)	2413	2301	1944	2567	2646	2204
Hairiness Index	**533**	**467**	**416**	**536**	**529**	**472**

APPENDIX 11

YARN QUALITY RESULTS WITH DCH 32 COTTON - Ne 80s / 7.38 TEX

Mixing - DCH 32 100%						
Spinning tm/tpi - 3.70/33.1						
Spinning spindle speed - 14000 rpm						
Sample specification	**D**	**E**	**F**	**G**	**H**	**I**
Number of Licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speed (rpm)	755	755	755	1060	840	590
	1202	1202	1202	-	-	-
	1516	1516	1516	-	-	-
Delivery speed (m/min)	50	75	100	50	50	50
Production rate (kg/hr)	**10**	**15**	**20**	**10**	**10**	**10**
Yarn Lea Count and Strength results:						
English count (Ne)	78.3	78.9	78.6	78.7	78.7	79.5
Strength in pounds	35.1	35.1	34	34.3	35.4	35.3
CSP	2748	2769	2672	2699	2786	2806
Corrected CSP	2726	2755	2654	2683	2769	2800
Count CV%	1.9	1.6	2.3	1.9	1.7	1.7
Strength CV%	4.8	3.7	6.2	5.6	3.8	4.3
Yarn Evenness and Imperfections (UT3):						
Yarn U%	13.44	13.75	14.11	13.5	12.96	13.2
Uster CV%	17.42	17.96	18.48	17.36	16.72	17.03
Thin (-50%)	62	60	91	72	37	47
Thick (50%)	547	709	853	541	426	471
Neps (+200%)	1260	1644	1900	1064	975	1086
Total	1869	2413	2844	1677	1438	1604
Single yarn strength						
Breaking force in gms	130.83	126.96	124.08	137.93	130.71	130.05
RKM	17.77	16.55	16.12	18.08	17.15	17.08
Elongation %	6.46	6.26	6.35	5.92	5.99	6.09

APPENDIX 12

YARN CLASSIMAT FAULTS FOR Ne 80s / 7.38 tex YARN

Classimat fault class	Sample Identification					
	D	E	F	G	H	I
Number of Licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speed (rpm)	755	755	755	1060	840	590
	1202	1202	1202	-	-	-
	1516	1516	1516	-	-	-
Delivery speed (m/min)	50	75	100	50	50	50
Production (kg/hr)	**10**	**15**	**20**	**10**	**10**	**10**
A1	5901	5718	9683	3838	3193	3531
A2	1136	1196	2364	728	609	681
A3	105	119	261	82	79	66
A4	14	15	27	10	18	14
B1	270	216	556	226	164	143
B2	135	134	300	121	113	87
B3	47	59	102	55	58	40
B4	20	26	28	30	30	16
C1	55	42	144	149	32	16
C2	19	23	35	31	24	12
C3	11	15	11	17	20	11
C4	5	10	6	10	9	8
D1	33	26	122	193	17	12
D2	9	8	22	9	12	11
D3	6	6	7	3	11	9
D4	5	3	2	1	5	4
E	43	37	193	491	14	20
F	128	17	207	66	26	19
G	19	6	50	17	3	4
H1	368	331	569	196	231	136
H2	7	12	6	13	10	2
I1	311	305	472	163	198	94
I2	7	10	6	13	10	2
Total faults	8654	8334	15173	6462	4886	4938

APPENDIX 13

ZWEIGLE HAIRINESS RESULTS FOR Ne 80s / 7.38 tex YARN

SAMPLE IDENTIFICATION	D	E	F	G	H	I
Number of Licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds	755	755	755	**1**	**1**	**1**
	1202	1202	1202	1060	840	590
	1516	1516	1516	-	-	-
				-	-	-
Delivery speed m/min	50	75	100	50	50	50
Production in kg/hr	**10**	**15**	**20**	**10**	**10**	**10**
1 mm	13016	12874	12624	12409	11980	12416
2 mm	1356	1287	1384	1205	1214	1292
3 mm	760	711	806	702	658	655
4 mm	694	688	734	656	613	572
6 mm	213	225	220	198	189	169
8 mm	71	74	73	64	61	56
10 mm	3.6	3.2	3.1	2.6	2.3	2.5
12 mm	0.1	0	0.1	0	0.1	0
15 mm	0	0	0	0	0	0
18 mm	0	0	0	0	0	0
21 mm	0	0	0	0	0	0
25 mm	0	0	0	0	0	0
Hairs / 100 m (>3mm)	1741	1700	1836	1623	1523	1454
Hairiness index	351	371	361	332	316	286

APPENDIX -14

Ne 20s – Ratings of Knitted Fabric Regularity

SAMPLE IDENTIFICATION	A	B	C	J	K	L
Number of Licker-ins	3	3	3	1	1	1
Licker-in speeds	*	*	*	1440	1080	840
Production in kg/hr	30	45	60	30	30	30
Judge 1	5	1	4	6	3	2
Judge 2	1	4	5	6	3	2
Judge 3	1	4	2	5	3	6
Judge 4	2	4	6	5	3	1
Judge 5	6	1	4	5	3	2
Judge 6	1	4	6	5	2	3
Judge 7	3	4	5	6	1	2
Judge 8	2	4	6	3	1	5
Judge 9	6	4	5	3	2	1
Judge 10	2	4	6	5	3	1
Rank total	29	34	49	49	24	25
Rank	3	4	6	6	1	2

Ne 20s – Ratings for Knitted Fabric Cleanliness

SAMPLE IDENTIFICATION	A	B	C	J	K	L
Number of Licker-ins	3	3	3	1	1	1
Licker-in speeds	*	*	*	1440	1080	840
Production in kg/hr	30	45	60	30	30	30
Judge 1	2	5	6	3	4	1
Judge 2	1	3	6	5	2	4
Judge 3	1	4	6	5	3	2
Judge 4	1	3	6	5	4	2
Judge 5	1	3	2	5	4	6
Judge 6	1	4	6	5	3	2
Judge 7	3	4	5	6	1	2
Judge 8	2	3	6	4	1	5
Judge 9	1	4	5	6	2	3
Judge 10	1	3	6	5	4	2
Rank total	14	36	54	49	28	29
Rank	1	4	6	5	2	3

* The Triple licker-in speeds (rolls 1, 2, 3) were 982, 1560, 1960 respectively.

APPENDIX -15

Ne 80s – Ratings of Knitted Fabric Regularity

SAMPLE IDENTIFICATION	D	E	F	G	H	I
Number of Licker-ins	3	3	3	1	1	1
Licker-in speeds	*	*	*	1080	840	590
Production in kg/hr	10	15	20	10	10	10
Judge 1	1	5	4	3	2	6
Judge 2	1	5	6	2	3	4
Judge 3	2	6	3	1	4	5
Judge 4	1	5	3	2	4	6
Judge 5	1	5	4	2	3	6
Judge 6	1	6	4	3	2	5
Judge 7	1	6	5	2	3	4
Judge 8	1	6	5	2	4	3
Judge 9	1	5	3	2	4	6
Judge 10	1	5	2	3	4	6
Rank total	11	54	39	22	33	51
Rank	1	6	4	2	3	5

Ne 80s – Ratings for Knitted Fabric Cleanliness

SAMPLE IDENTIFICATION	D	E	F	G	H	I
Number of Licker-ins	3	3	3	1	1	1
Licker-in speeds	*	*	*	1080	840	590
Production in kg/hr	10	15	20	10	10	10
Judge 1	1	5	6	3	4	2
Judge 2	1	6	5	2	3	4
Judge 3	2	6	4	1	3	5
Judge 4	1	4	2	3	5	6
Judge 5	1	5	6	2	3	4
Judge 6	1	6	5	3	2	4
Judge 7	1	6	4	2	3	5
Judge 8	2	4	6	1	3	5
Judge 9	1	6	5	3	2	4
Judge 10	1	6	5	2	3	4
Rank total	12	54	48	22	31	43
Rank	1	6	5	2	3	4

* The Triple licker-in speeds (rolls 1,2,3) were 755, 1202 and 1516 respectively.

APPENDIX 16

20s Ne Knitted Fabric Pilling Results

SAMPLE IDENTIFICATION		A	B	C	J	K	L
Number of licker-ins		**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds		982	982	982	1440	1080	840
		1560	1560	1560	-	-	-
		1960	1960	1960	-	-	-
Delivery speed m/min		100	150	200	100	100	100
Production in kg/hr		**30**	**45**	**60**	**30**	**30**	**30**
Fabric pilling tendency	RATING						
Very severe pilling	1	-	-	YES	-	-	-
Severe pilling	2	YES	YES	-	-	YES	-
Moderate pilling	3	-	-	-	YES	-	YES
Slight pilling	4	-	-	-	-	-	-
No pilling	5	-	-	-	-	-	-

80s Ne Knitted Fabric Pilling Results

SAMPLE IDENTIFICATION		D	E	F	G	H	I
Number of Licker-ins		**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds		755	755	755	1	1	1
		1202	1202	1202	1060	840	590
		1516	1516	1516	-	-	-
Delivery speed m/min		50	75	100	50	50	50
Production in kg/hr		**10**	**15**	**20**	**10**	**10**	**10**
Fabric pilling tendency	RATING						
Very severe pilling	1	-	-	-	-	-	-
Severe pilling	2	YES	YES	YES	YES	YES	YES
Moderate pilling	3	-	-	-	-	-	-
Slight pilling	4	-	-	-	-	-	-
No pilling	5	-	-	-	-	-	-

APPENDIX – 17

Ne 20s – FIBRE EXTENT RATIO IN YARNS

SAMPLE IDENTIFICATION	A	B	C	J	K	L
Number of Licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds	*	*	*	1440	1080	840
Production in kg/hr	**30**	**45**	**60**	**30**	**30**	**30**
Mean Fibre Extent Ratio % for each length group						
Fibre length group 0-15 mm	7.19	8.21	7.35	9.41	8.12	8.19
15-25 mm	4.97	4.82	6.89	5.69	5.88	5.58
>25 mm	4.35	4.41	4.53	4.12	3.93	3.71
Mean FER %	**4.82**	**4.86**	**5.59**	**5.36**	**5.27**	**4.93**
Number of fibres in each length group						
Fibre length group 0-15 mm	3	3	1	6	1	7
15-25 mm	12	12	13	9	16	8
>25 mm	10	10	11	10	8	10

* The Triple licker-in speeds (rolls 1, 2, 3) were 982, 1560, 1960 respectively.

Ne 80s – FIBRE EXTENT RATIO IN YARNS

SAMPLE IDENTIFICATION	D	E	F	G	H	I
Number of Licker-ins	**3**	**3**	**3**	**1**	**1**	**1**
Licker-in speeds	**	**	**	1080	840	590
Production in kg/hr	**10**	**15**	**20**	**10**	**10**	**10**
Mean Fibre Extent Ratio % for each length group						
Fibre length group 0-15 mm	9.54	7.13	7.40	9.64	6.23	7.80
15-25 mm	4.92	4.29	5.18	6.83	4.95	4.68
>25 mm	3.83	3.69	3.34	3.53	2.77	2.61
Mean FER %	**4.65**	**4.58**	**4.42**	**5.52**	**4.07**	**3.88**
Number of fibres in each length group						
Fibre length group 0-15 mm	3	7	4	8	6	4
15-25 mm	13	10	12	8	12	10
>25 mm	9	8	9	9	7	10

** The Triple licker-in speeds (rolls 1,2,3) were 755, 1202 and 1516 respectively.

APPENDIX 18

NHH 44 – FIBRE TUFTS DISTRIBUTION ON LICKER-IN

Licker-in type	Licker-in speed	Production in kg /hr	Number of tufts per 0.1 gram		
			< 3 mm	3 - 9 mm	> 9 mm
Single Licker-in	840	10	14	10	32
	840	20	20	14	50
	840	30	24	8	32
	1080	30	11	17	53
	1440	30	12	7	37
Triple Licker-in	Roll 1 *	10	31	72	79
	Roll 1 *	30	9	18	48
	Roll 1 *	60	2	18	70
	Roll 3 *	10	34	10	14
	Roll 3 *	30	14	10	28
	Roll 3 *	45	18	14	27
	Roll 3 *	60	18	22	74

** The Triple licker-in speeds (rolls 1 and 3) were 1024 and 2068 respectively

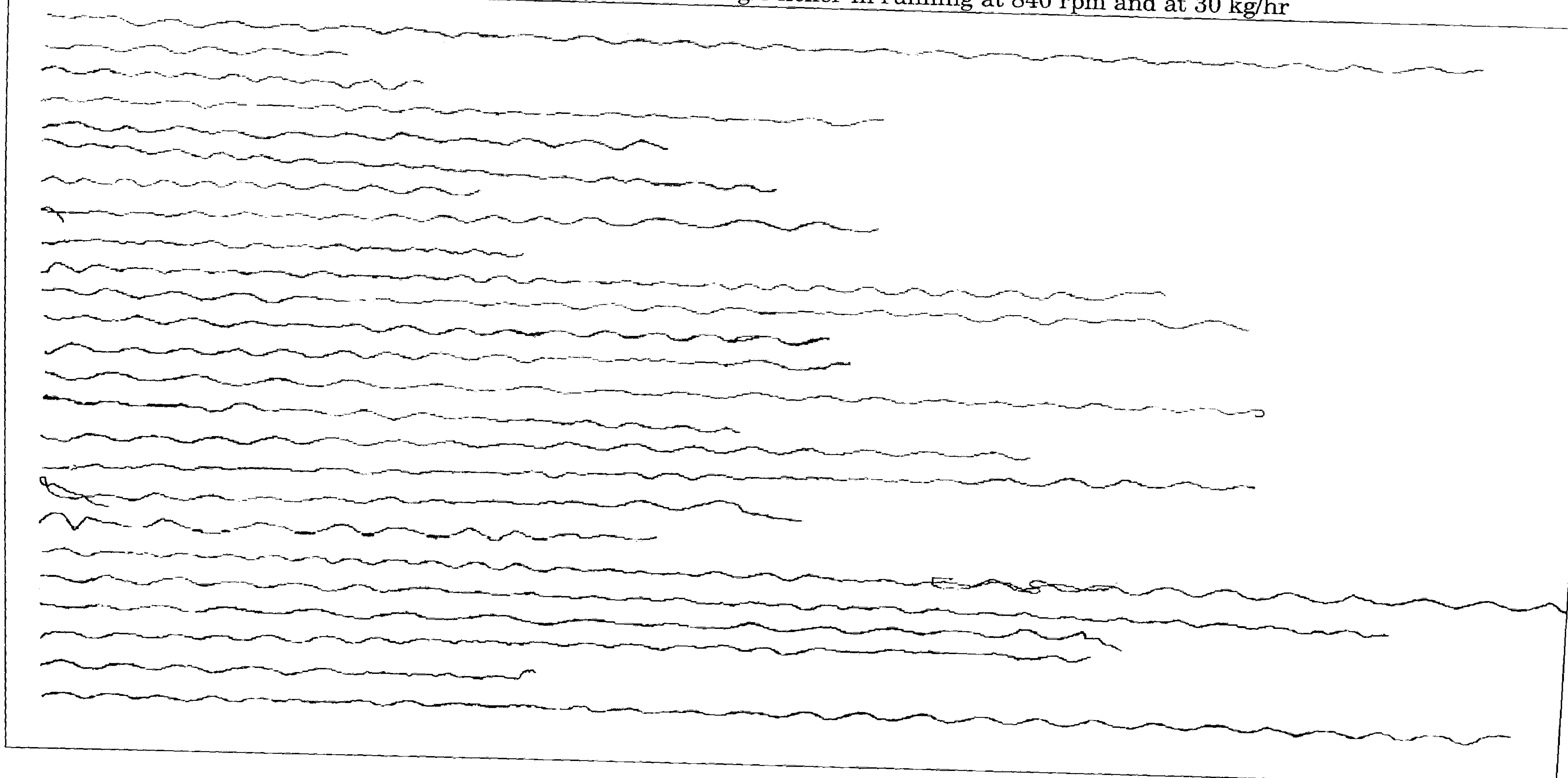
DCH 32 – FIBRE TUFTS DISTRIBUTION ON LICKER-IN

Licker-in type	Licker-in speed	Production in kg /hr	Number of tufts per 0.1 gram		
			< 3 mm	3 - 9 mm	> 9 mm
Single Licker-in	590	10	24	0	8
	840	10	20	0	20
	840	15	11	3	29
	840	20	16	8	35
	1080	10	20	0	39
Triple Licker-in	Roll 1 *	10	41	79	143
	Roll 1 *	20	17	43	111
	Roll 3 *	10	20	7	48
	Roll 3 *	15	20	39	102
	Roll 3 *	20	12	24	106

* The Triple licker-in speeds (rolls 1 and 3) were 785 and 1584 respectively

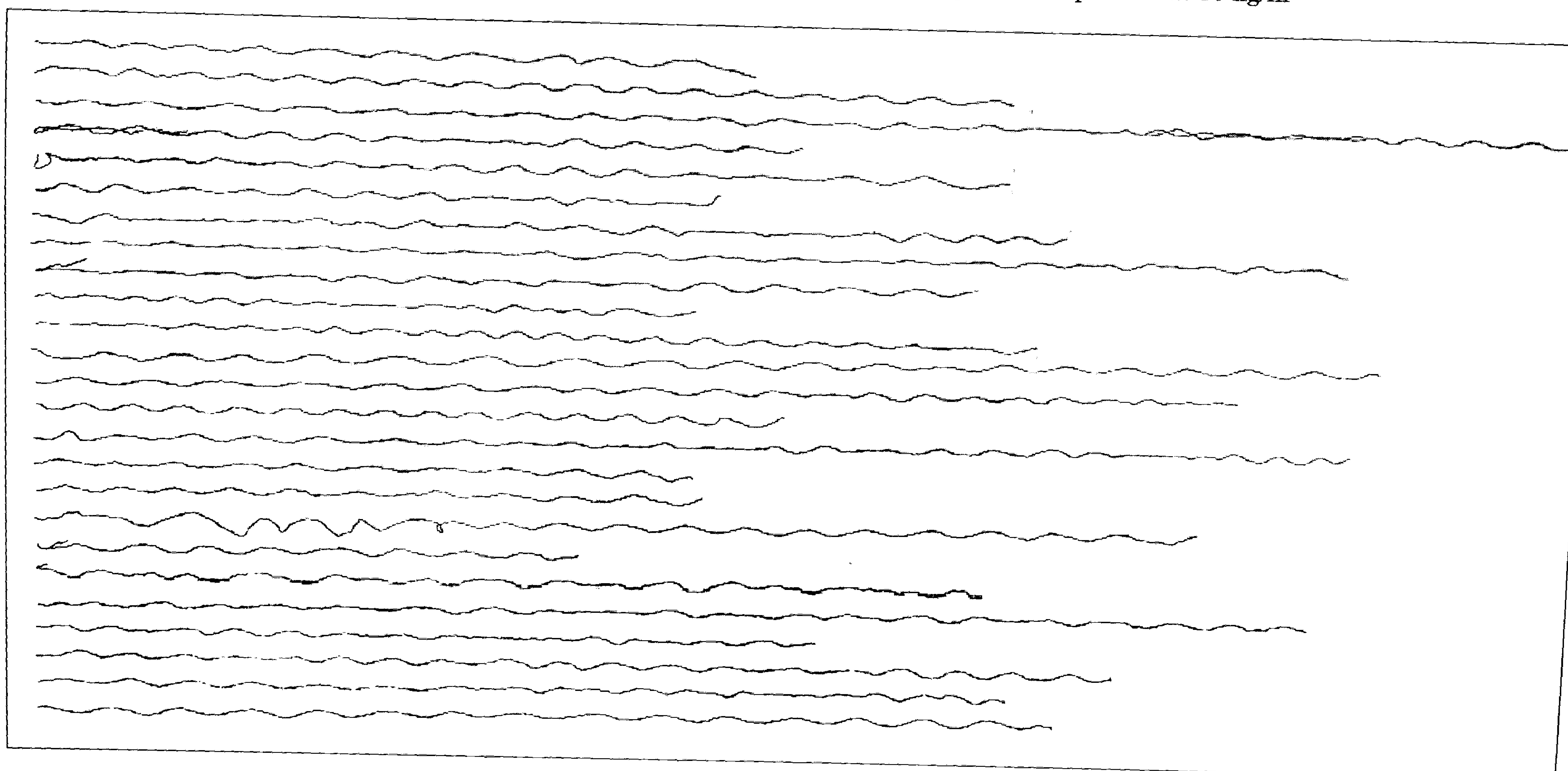
APPENDIX 19

Fibre configurations in Ne 20s yarn with single licker-in running at 840 rpm and at 30 kg/hr



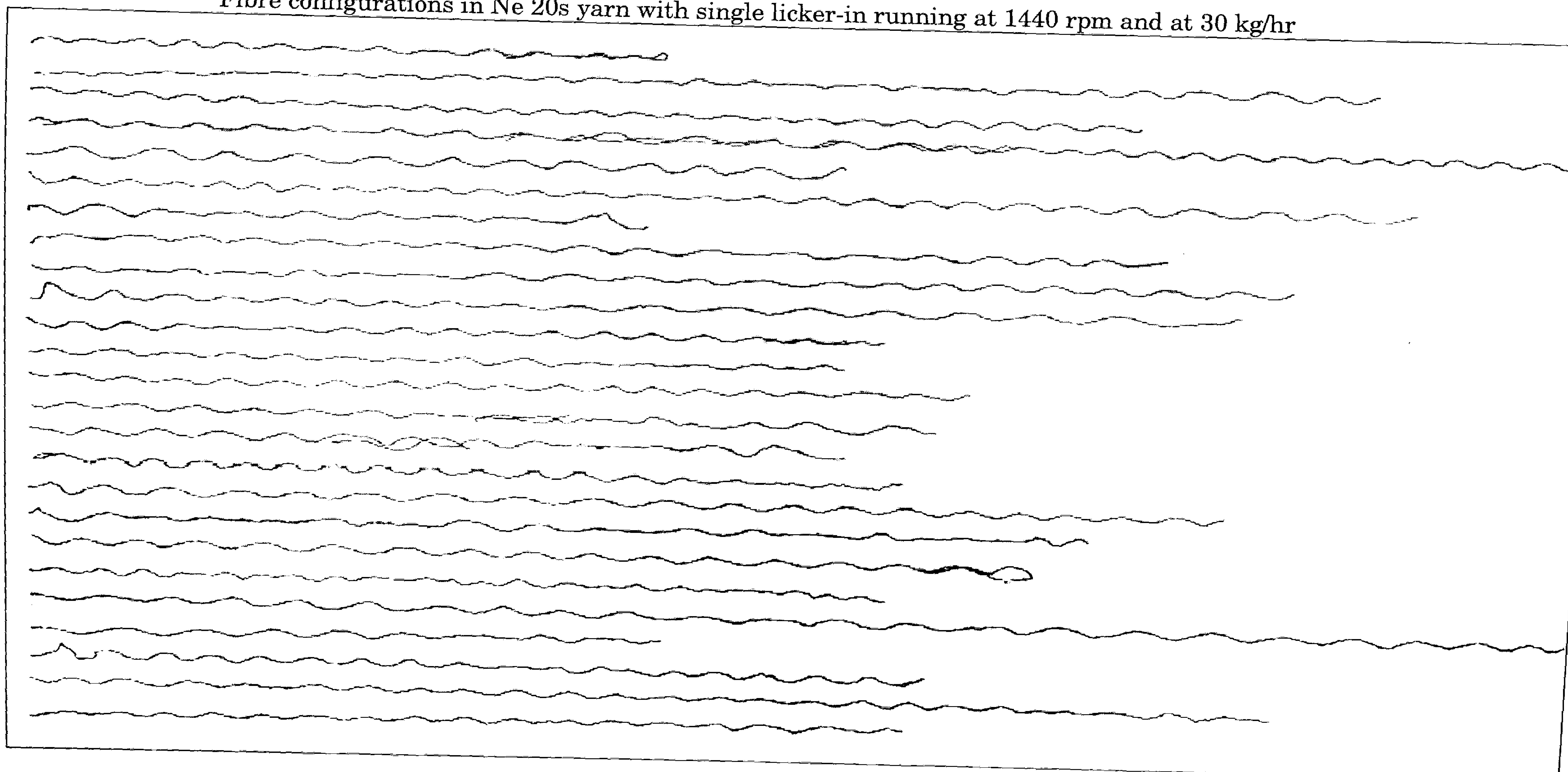
APPENDIX 20

Fibre configurations in Ne 20s yarn with single licker-in running at 1080 rpm and at 30 kg/hr



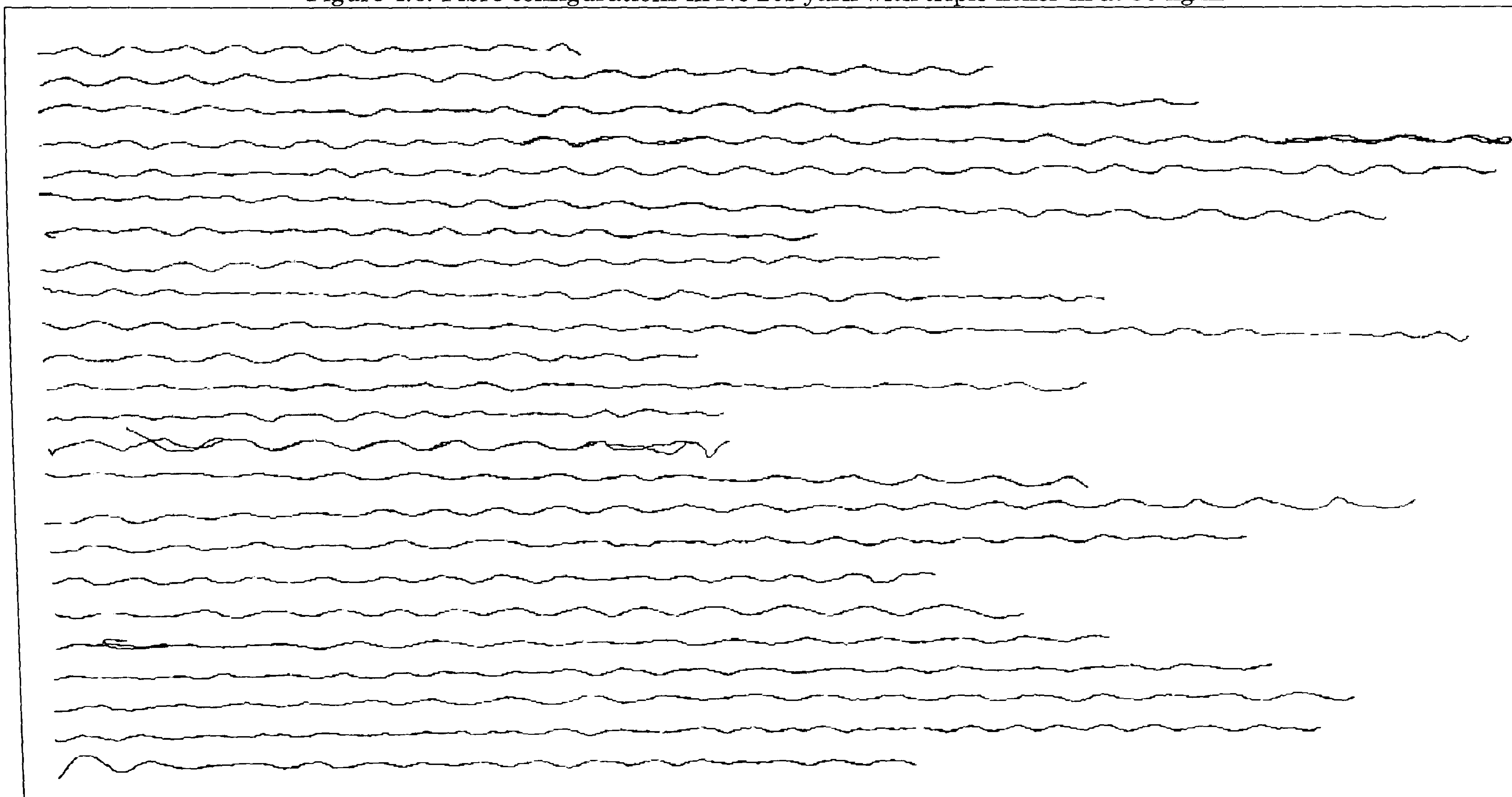
APPENDIX 21

Fibre configurations in Ne 20s yarn with single licker-in running at 1440 rpm and at 30 kg/hr



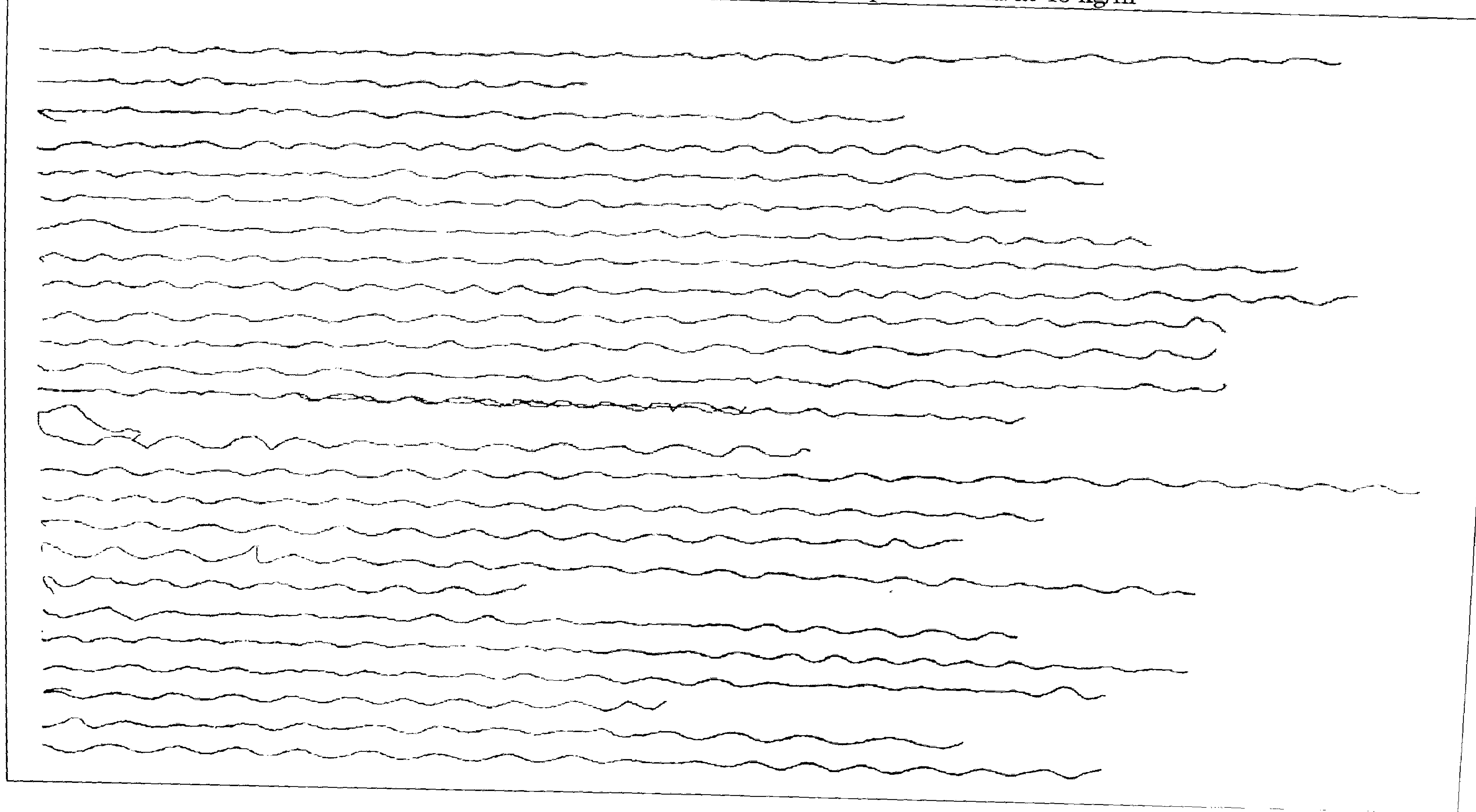
APPENDIX 22

Figure 4.6: Fibre configurations in Ne 20s yarn with triple licker-in at 30 kg/hr



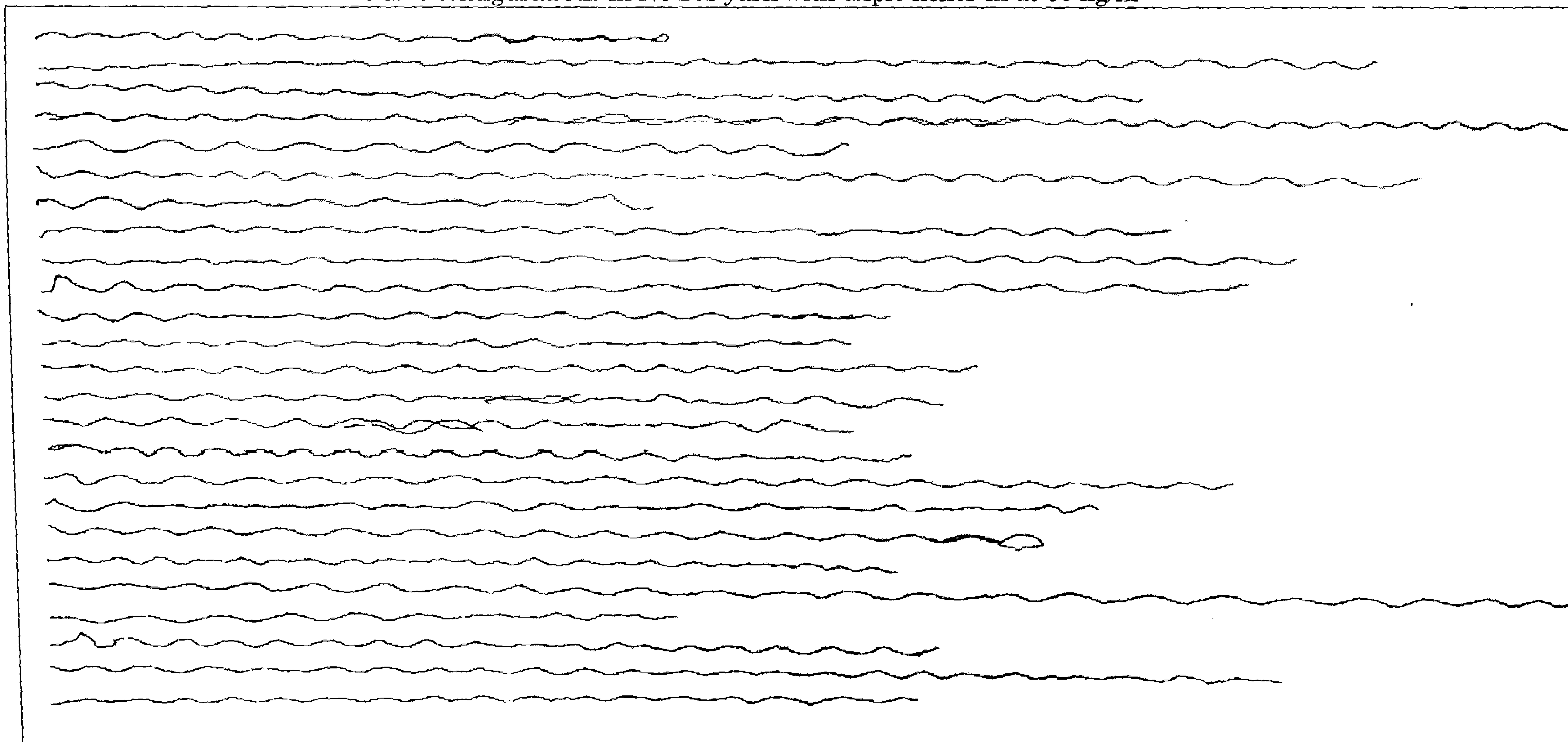
APPENDIX 23

Fibre configurations in Ne 20s yarn with triple licker-in at 45 kg/hr



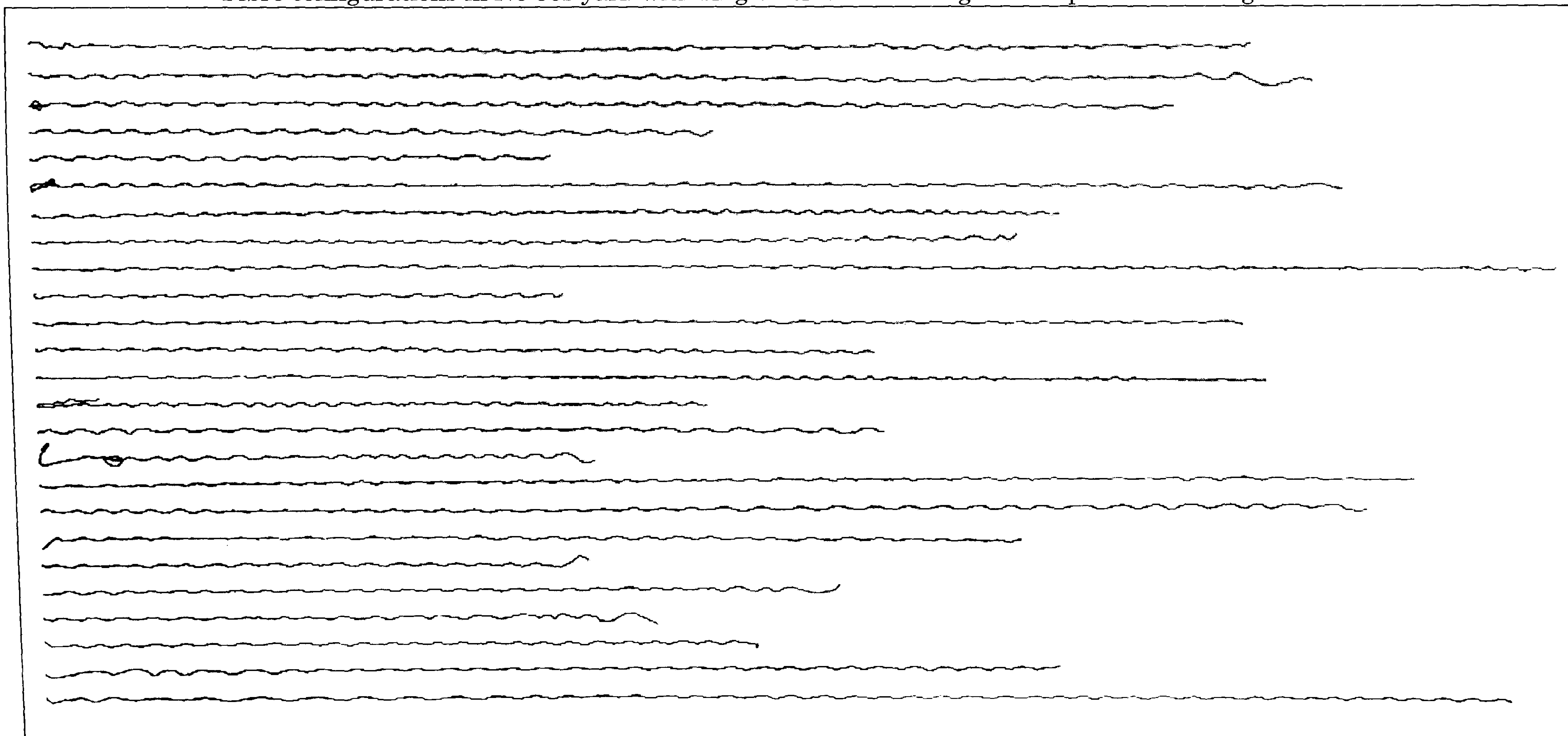
APPENDIX 24

Fibre configurations in Ne 20s yarn with triple licker-in at 60 kg/hr



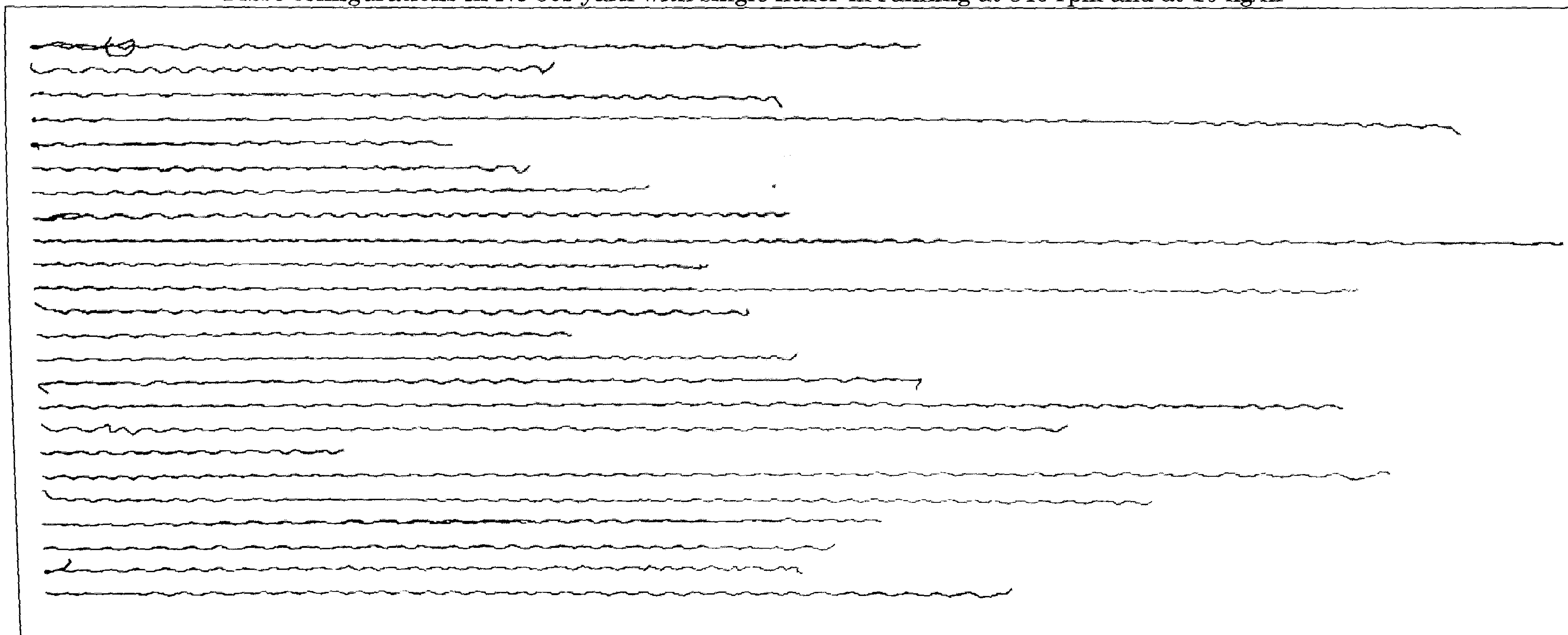
APPENDIX 25

Fibre configurations in Ne 80s yarn with single licker-in running at 590 rpm and at 10 kg/hr



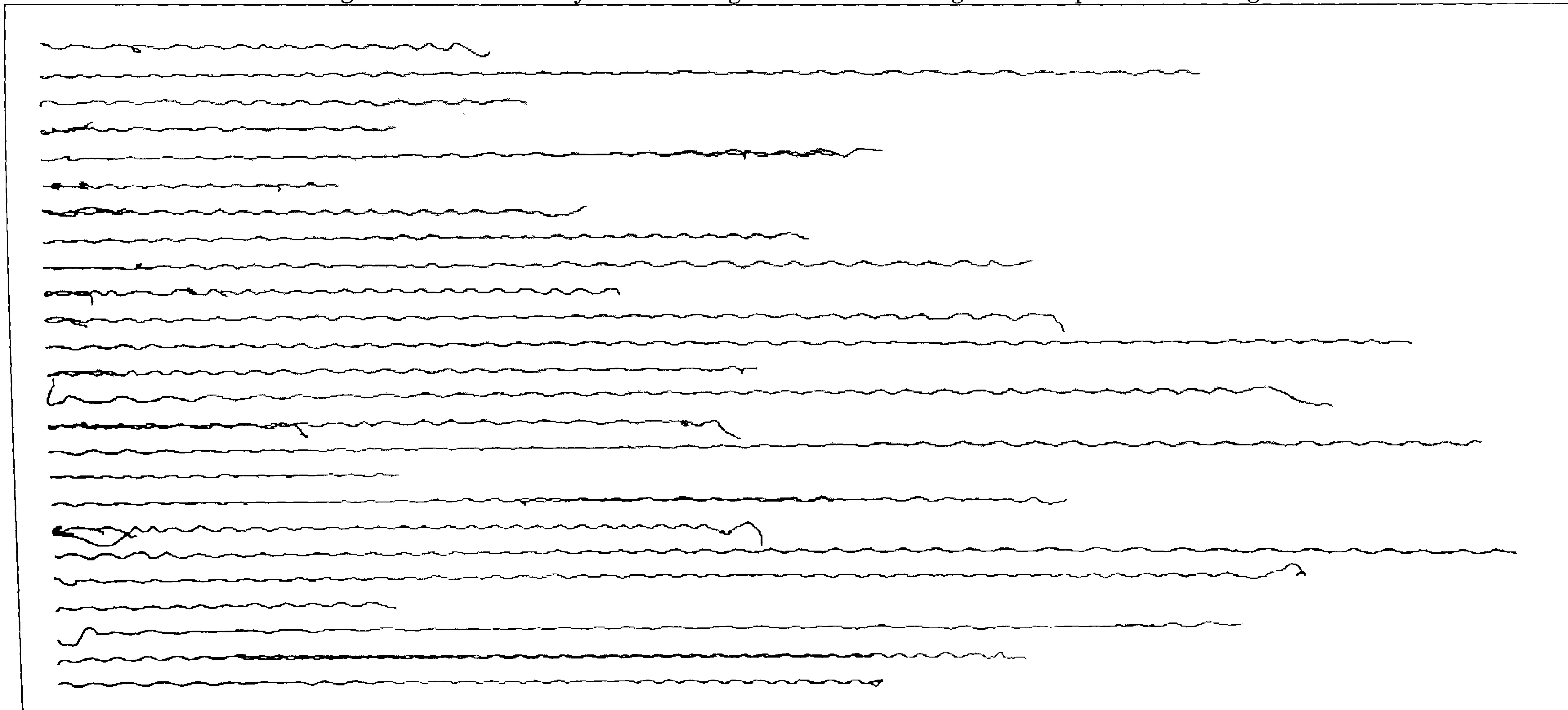
APPENDIX 26

Fibre configurations in Ne 80s yarn with single licker-in running at 840 rpm and at 10 kg/hr



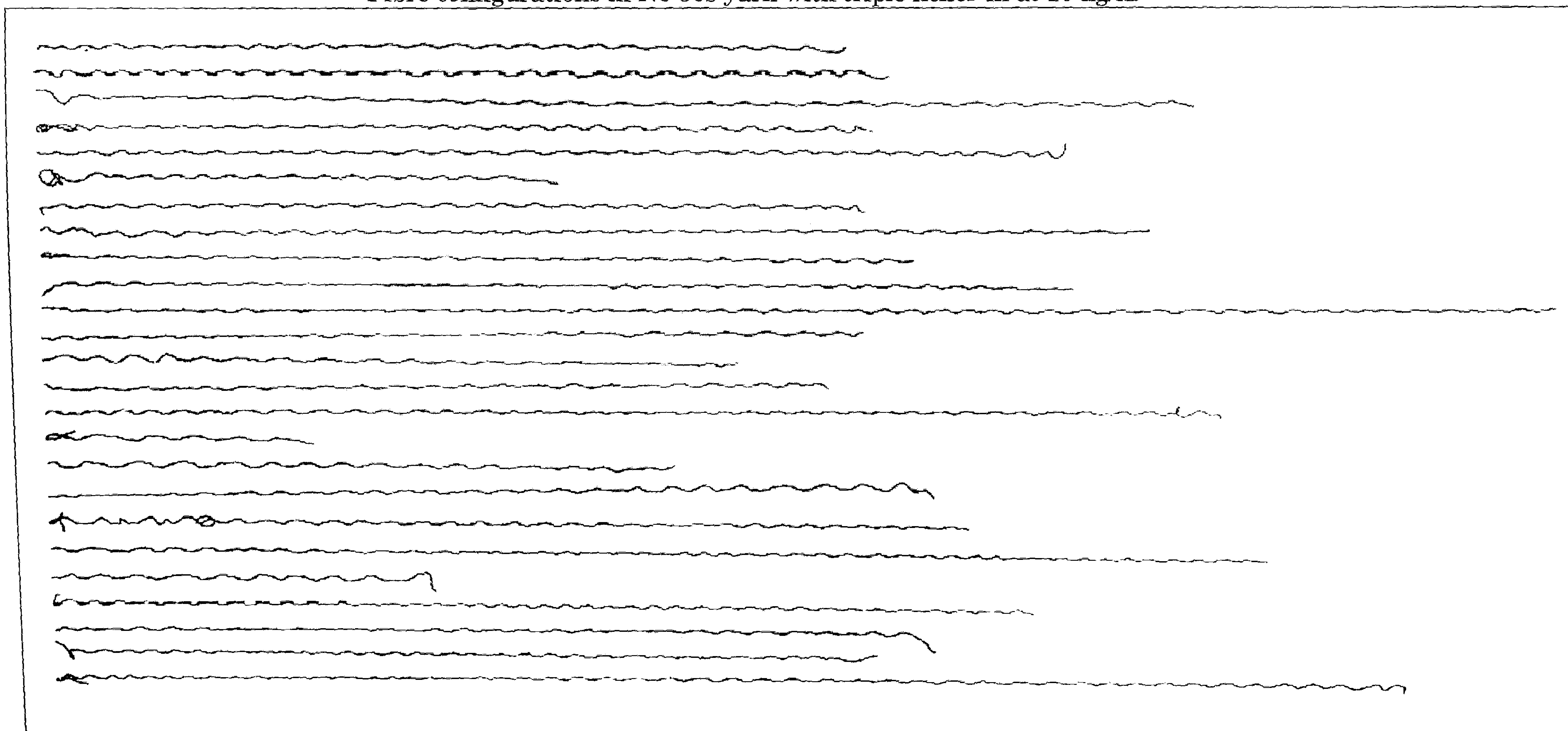
APPENDIX 27

Fibre configurations in Ne 80s yarn with single licker-in running at 1080 rpm and at 10 kg/hr



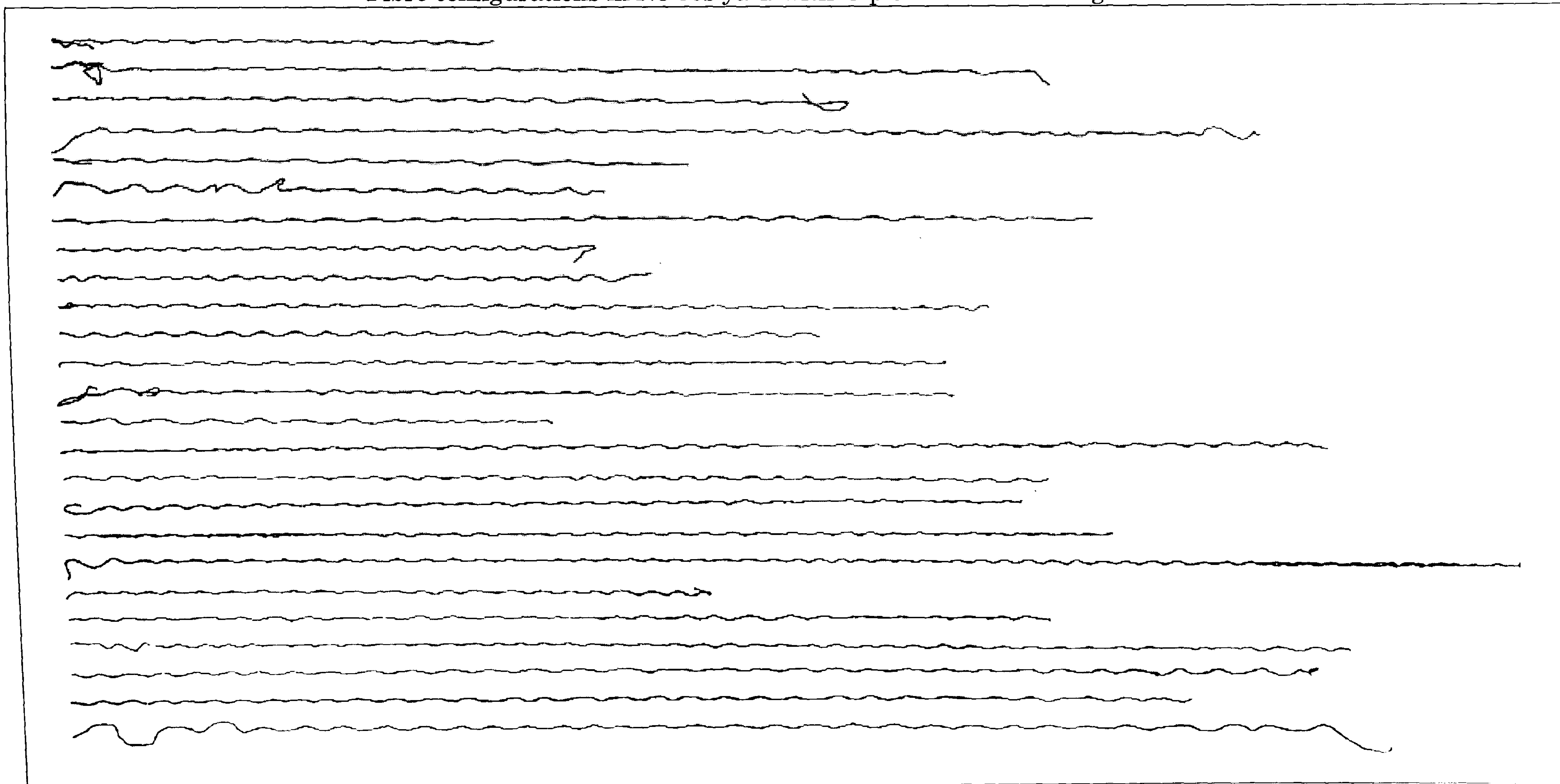
APPENDIX 28

Fibre configurations in Ne 80s yarn with triple licker-in at 10 kg/hr



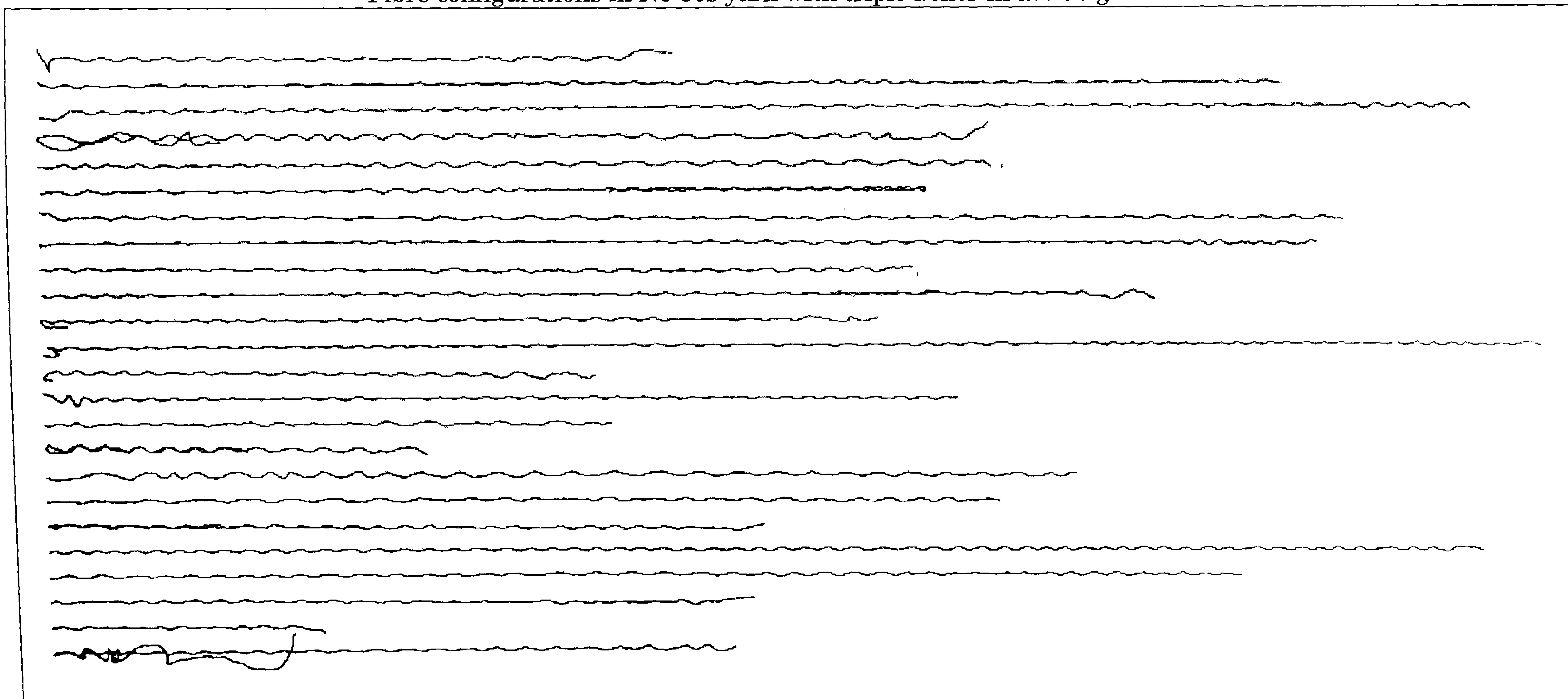
APPENDIX 29

Fibre configurations in Ne 80s yarn with triple licker-in at 10 kg/hr



APPENDIX 30

Fibre configurations in Ne 80s yarn with triple licker-in at 20 kg/hr



APPENDIX 31

FIBRE CONFIGURATIONS ON LICKER-IN WITH SINGLE AND TRIPLE LICKER-IN ARRANGEMENTS

Cotton	Licker-in Type	Licker-in Speed (rpm)	Production kg/hr	Mean Fibre Length (mm)	Mean Fibre Extent mm	Mean FE Ratio %	Fibre Projection in Y (mm)	Fibre Projection in X (mm)	Orientation angle in deg	Sample size
DCH 32	Single	590	10	27.73	18.99	30.77	18.80	3.72	6.91	25
		840	10	28.81	21.18	25.87	21.06	3.50	4.95	50
		1080	10	31.57	23.46	26.23	23.40	3.19	2.66	25
		840	20	31.99	22.01	29.33	21.79	3.44	5.70	25
	Triple	*	10	23.30	15.06	34.38	14.79	5.50	16.72	50
		*	15	22.37	15.64	29.17	15.38	4.77	14.85	25
		*	20	22.58	14.56	35.66	14.60	4.84	15.16	25
NHH 44	Single	840	30	26.03	18.42	28.10	17.88	4.66	9.71	50
		1080	30	27.60	18.33	33.33	18.11	4.30	7.42	25
		1440	30	25.27	18.70	26.03	18.41	3.74	6.68	25
		840	10	26.53	19.21	27.98	18.92	4.34	8.96	25
	Triple	**	30	24.11	15.64	34.54	15.80	4.47	12.35	50
		**	45	23.06	15.93	29.80	16.22	4.30	11.22	25
		**	60	23.71	16.67	30.35	16.98	4.16	9.016	25

* The Triple licker-in speeds (rolls 1,2,3) were 785, 1252 and 1584 respectively

** The Triple licker-in speeds (rolls 1,2,3) were 1024, 1632, and 2068 respectively

APPENDIX 32

CONFIGURATION OF FIBRES IN GROUP I, II AND III

Cotton	Licker-in Type	Licker-in Speed (rpm)	Production kg/hr	Group I fibres	Group II fibres	Group III fibres	Sample Size
DCH 32	Single	590	10	5	15	5	25
		840	10	**19**	**29**	**2**	**50**
		1080	10	8	15	2	25
		840	20	4	16	5	25
	Triple	*	10	**7**	**29**	**14**	**50**
		*	15	7	12	6	25
		*	20	2	17	6	25
NHH 44	Single	840	30	**18**	**24**	**8**	**50**
		1080	30	5	14	6	25
		1440	30	6	16	3	25
		840	10	6	15	4	25
	Triple	**	**30**	**10**	**28**	**12**	**50**
		**	45	6	17	2	25
		**	60	3	19	3	25

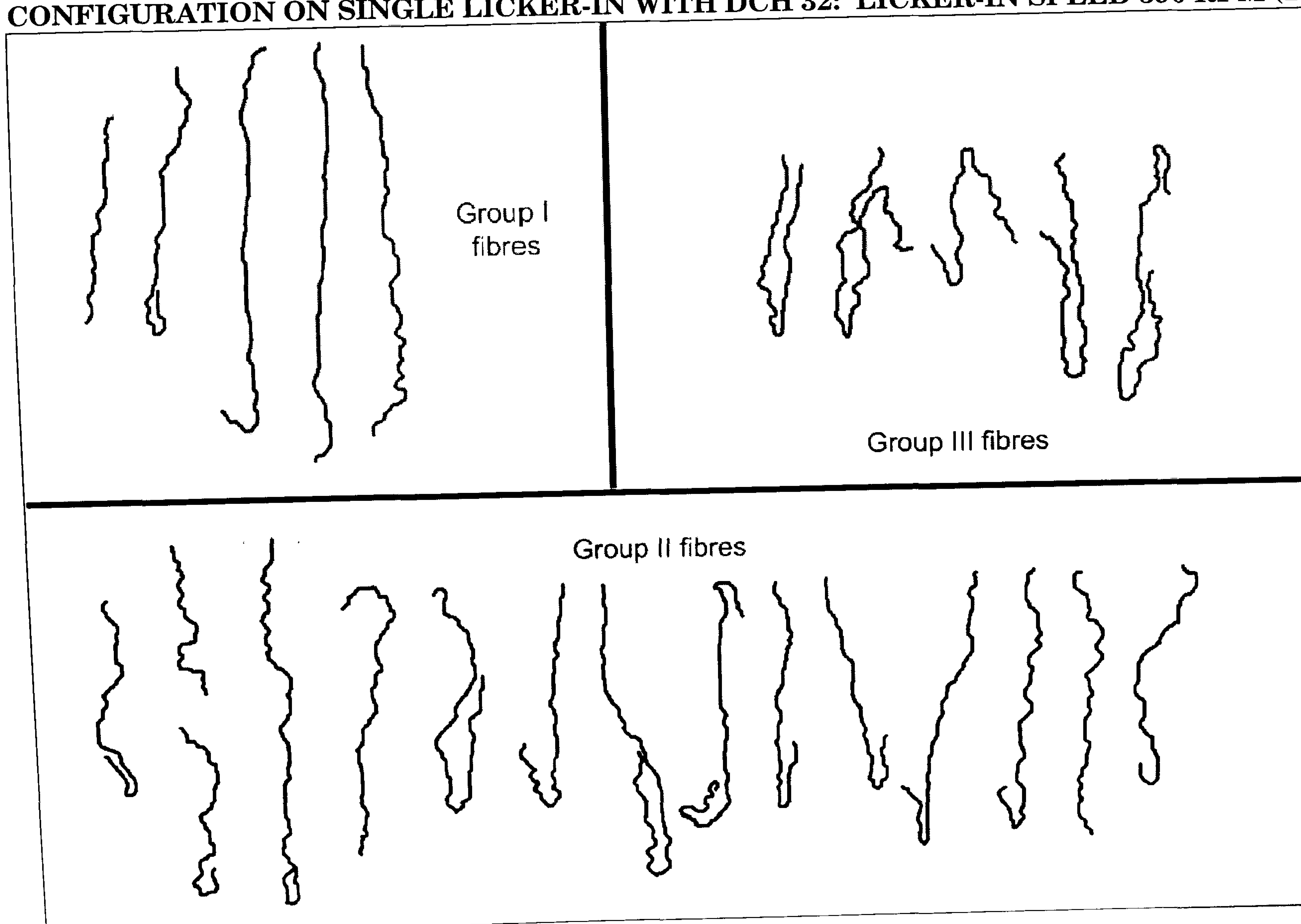
* The Triple licker-in speeds (rolls 1,2,3) were 785, 1252 and 1584 respectively

** The Triple licker-in speeds (rolls 1,2,3) were 1024, 1632, and 2068 respectively

Highlighted ones are the main experiments and have a higher sample size

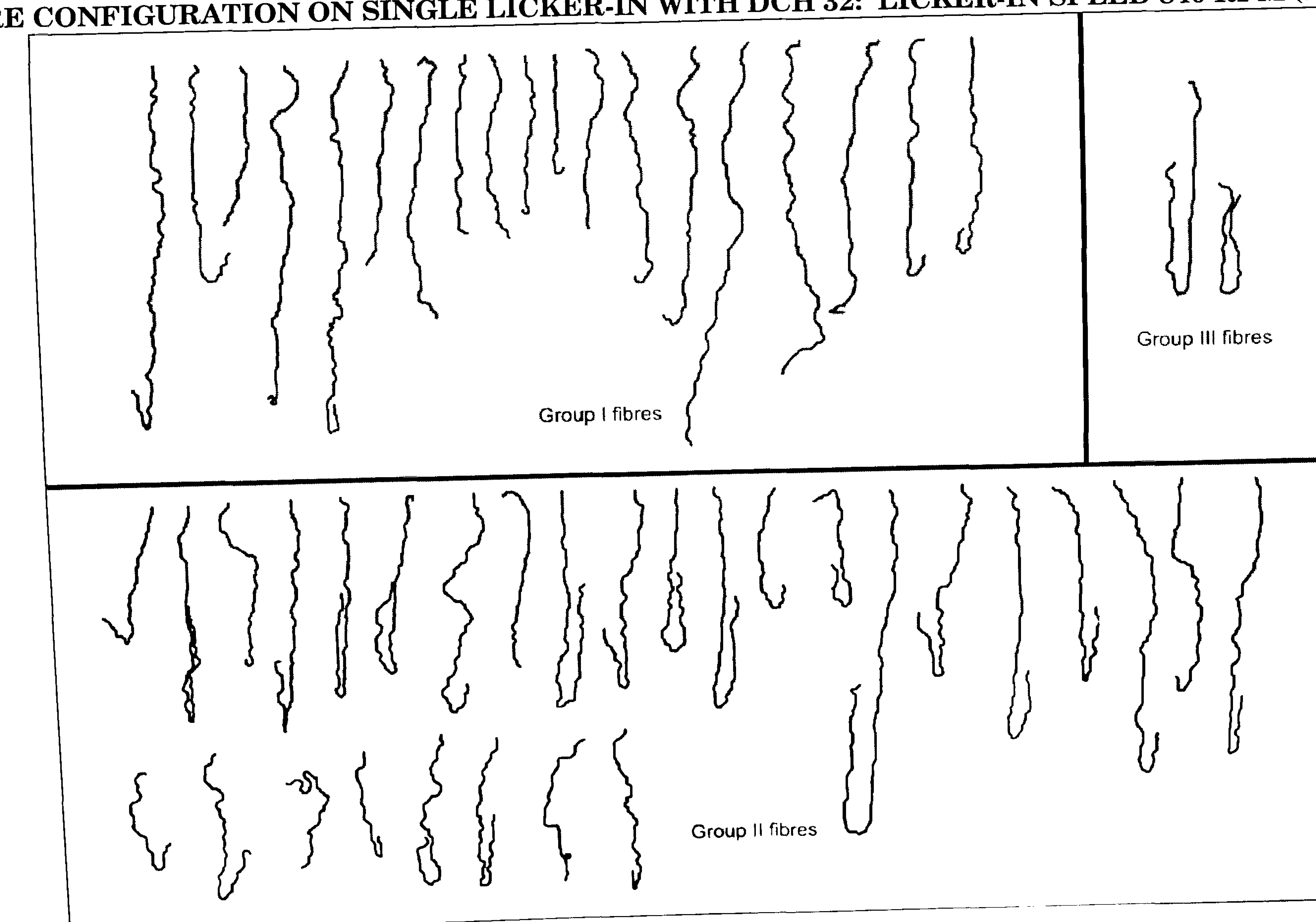
APPENDIX 33

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH DCH 32: LICKER-IN SPEED 590 RPM (10 kg /hr)



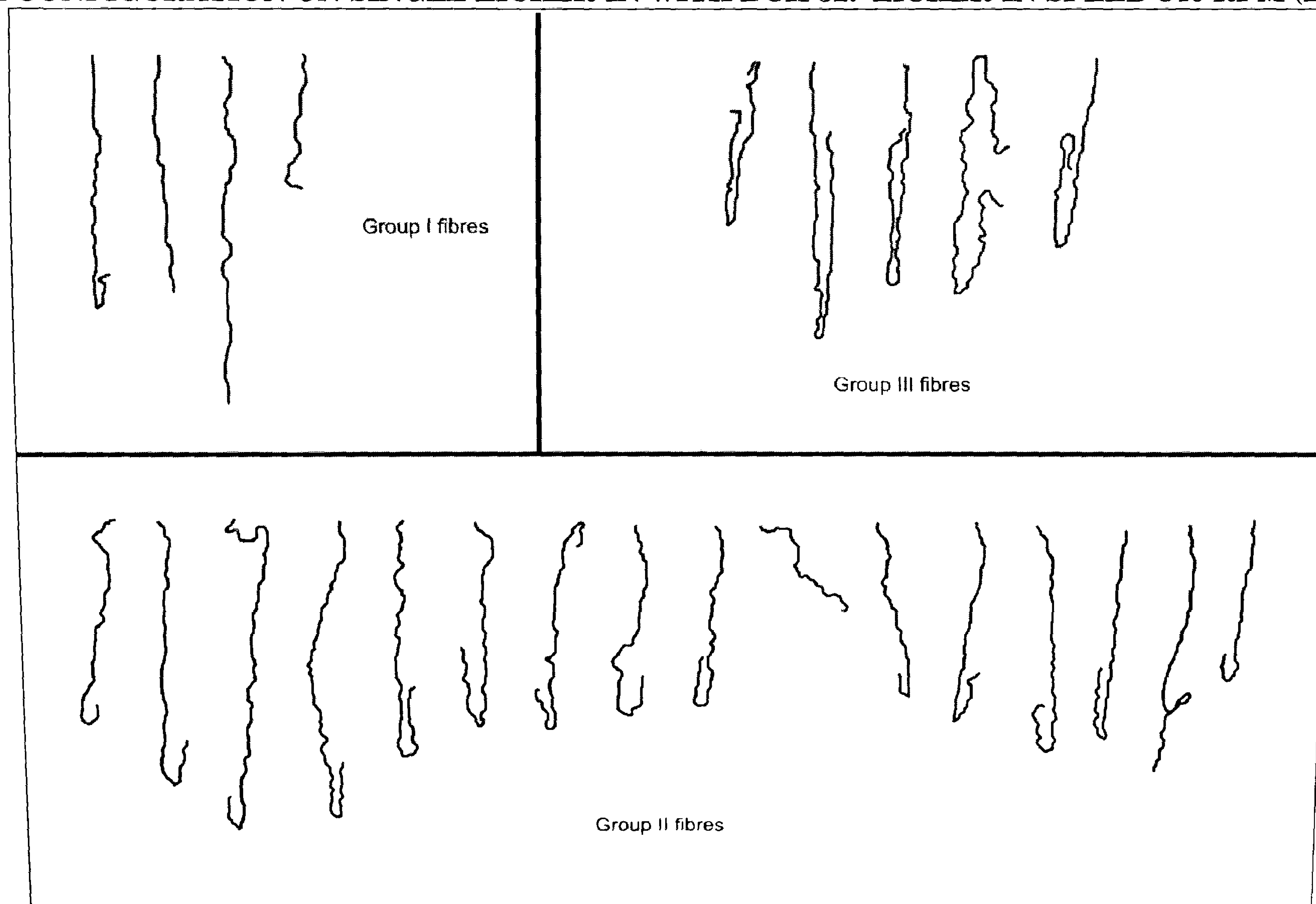
APPENDIX 34

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH DCH 32: LICKER-IN SPEED 840 RPM (10 kg/hr)



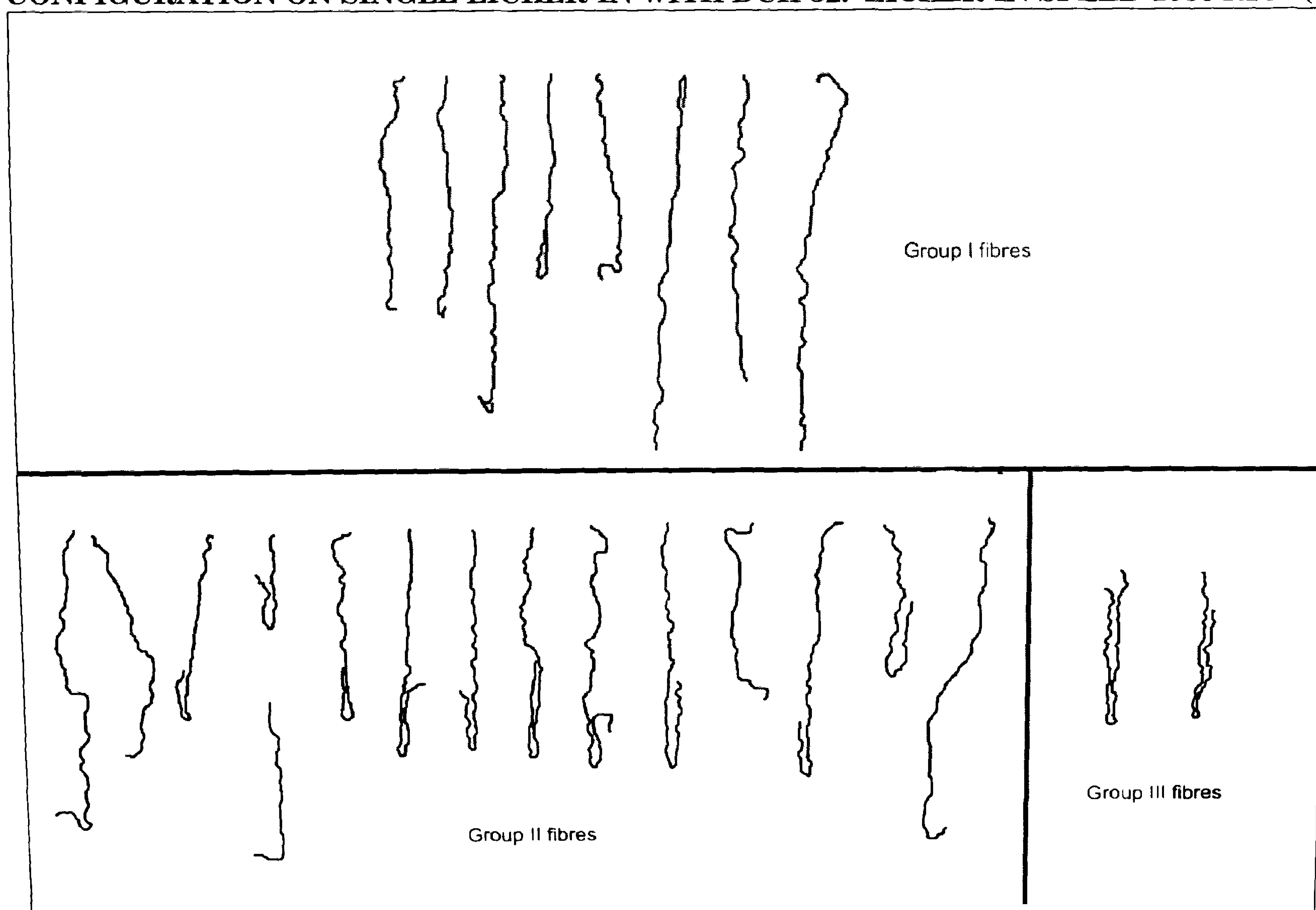
APPENDIX 35

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH DCH 32: LICKER-IN SPEED 840 RPM (20 kg/hr)



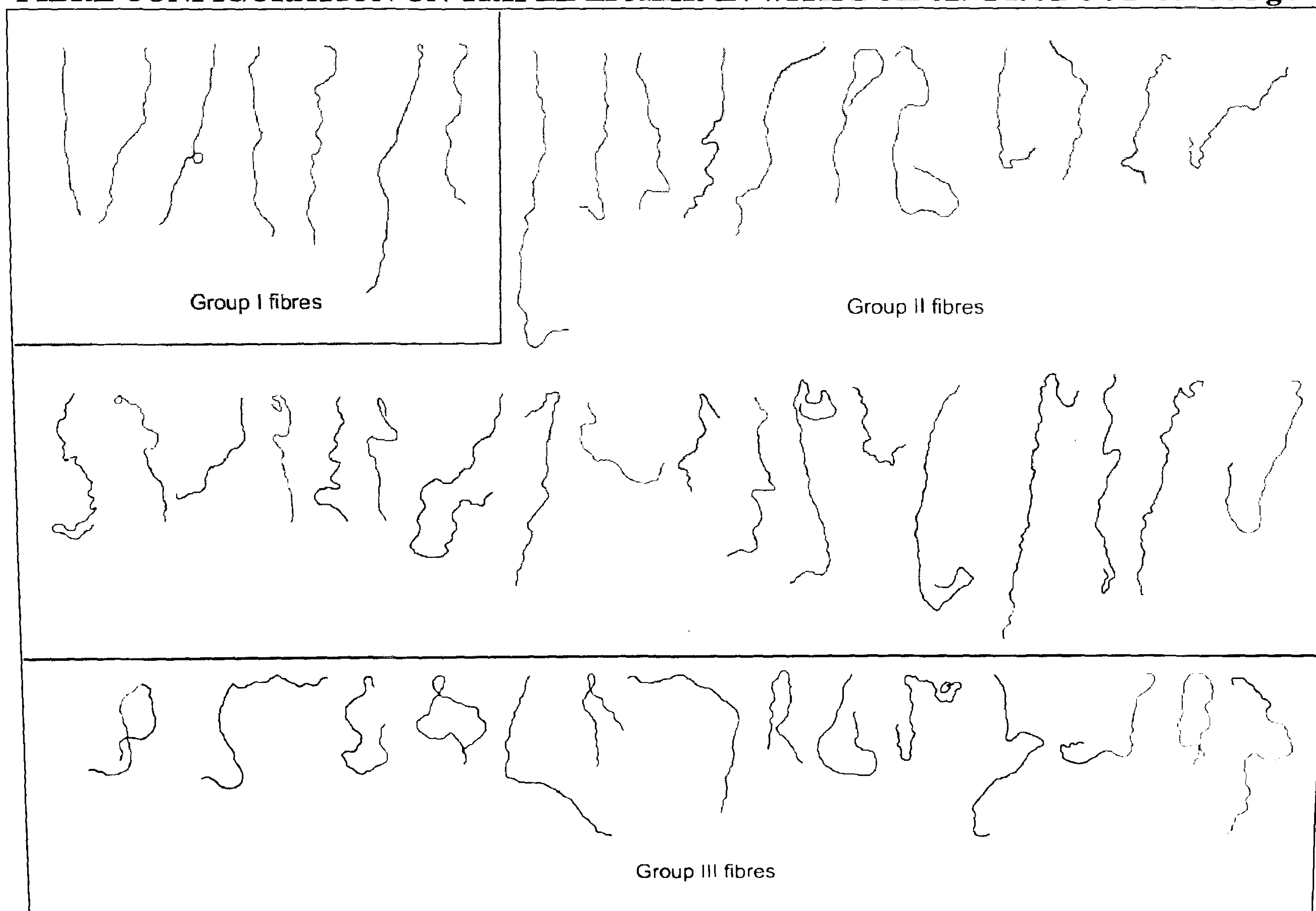
APPENDIX 36

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH DCH 32: LICKER-IN SPEED 1080 RPM (10 kg/hr)



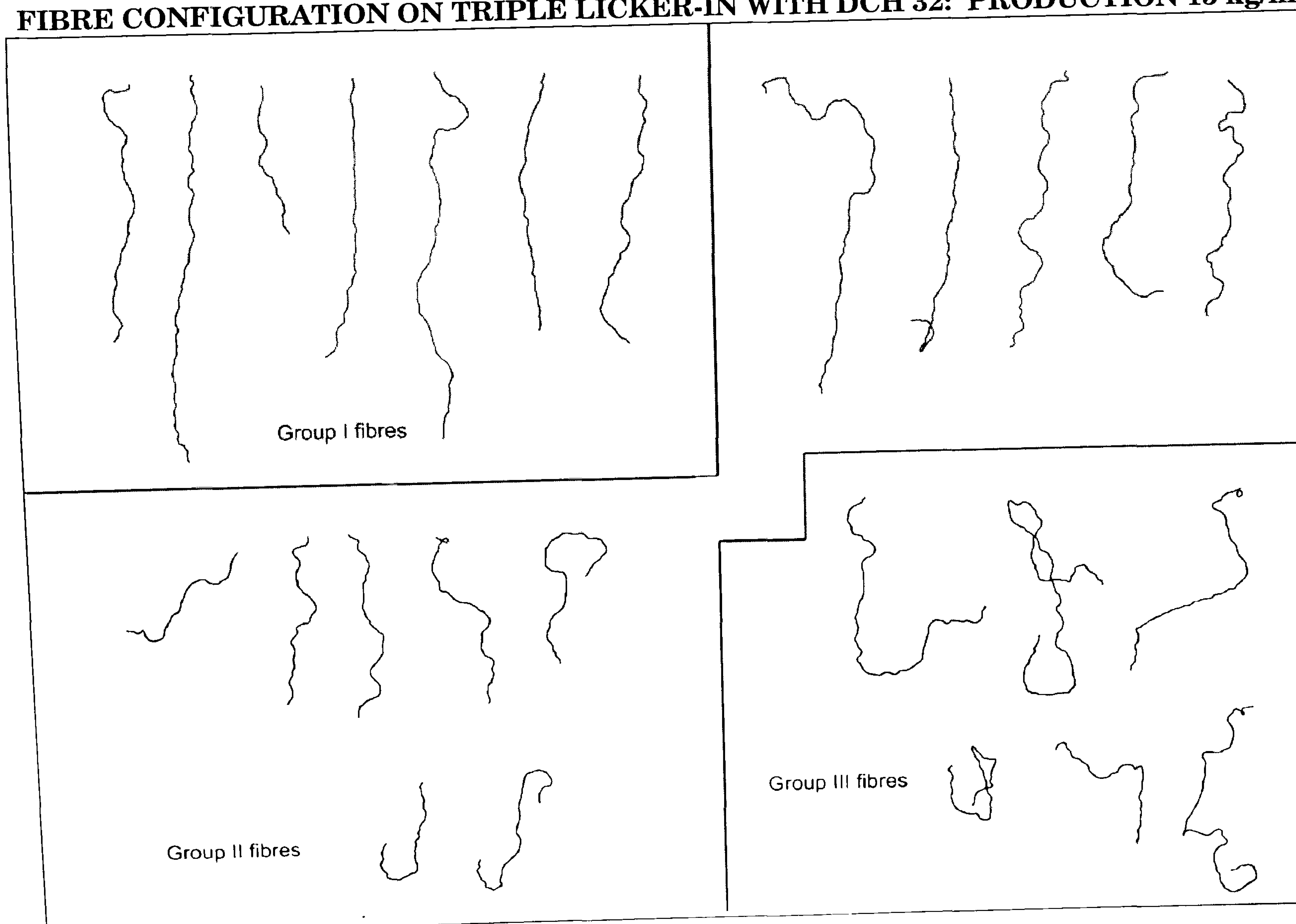
APPENDIX 37

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH DCH 32: PRODUCTION 10 kg/hr



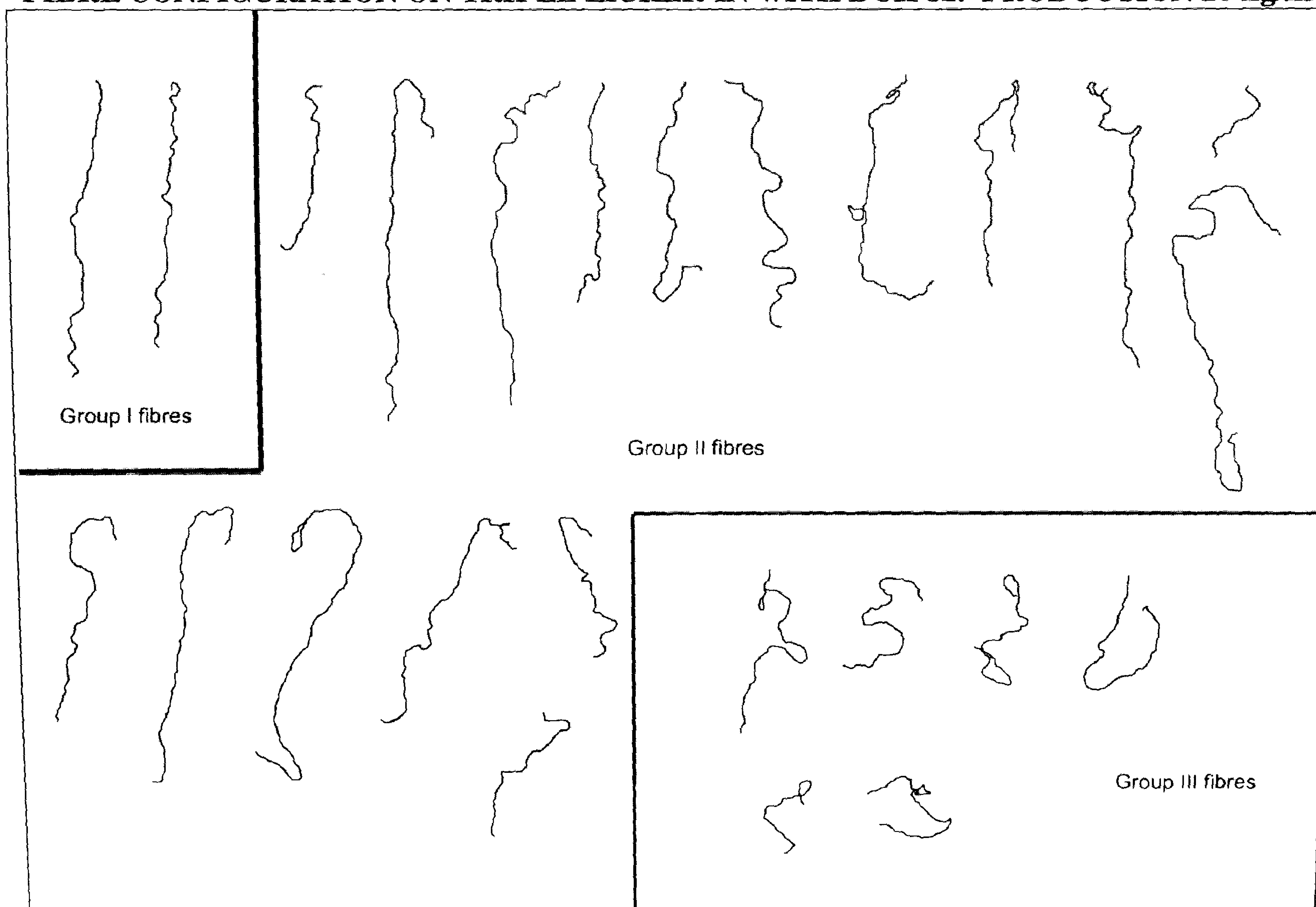
APPENDIX 38

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH DCH 32: PRODUCTION 15 kg/hr



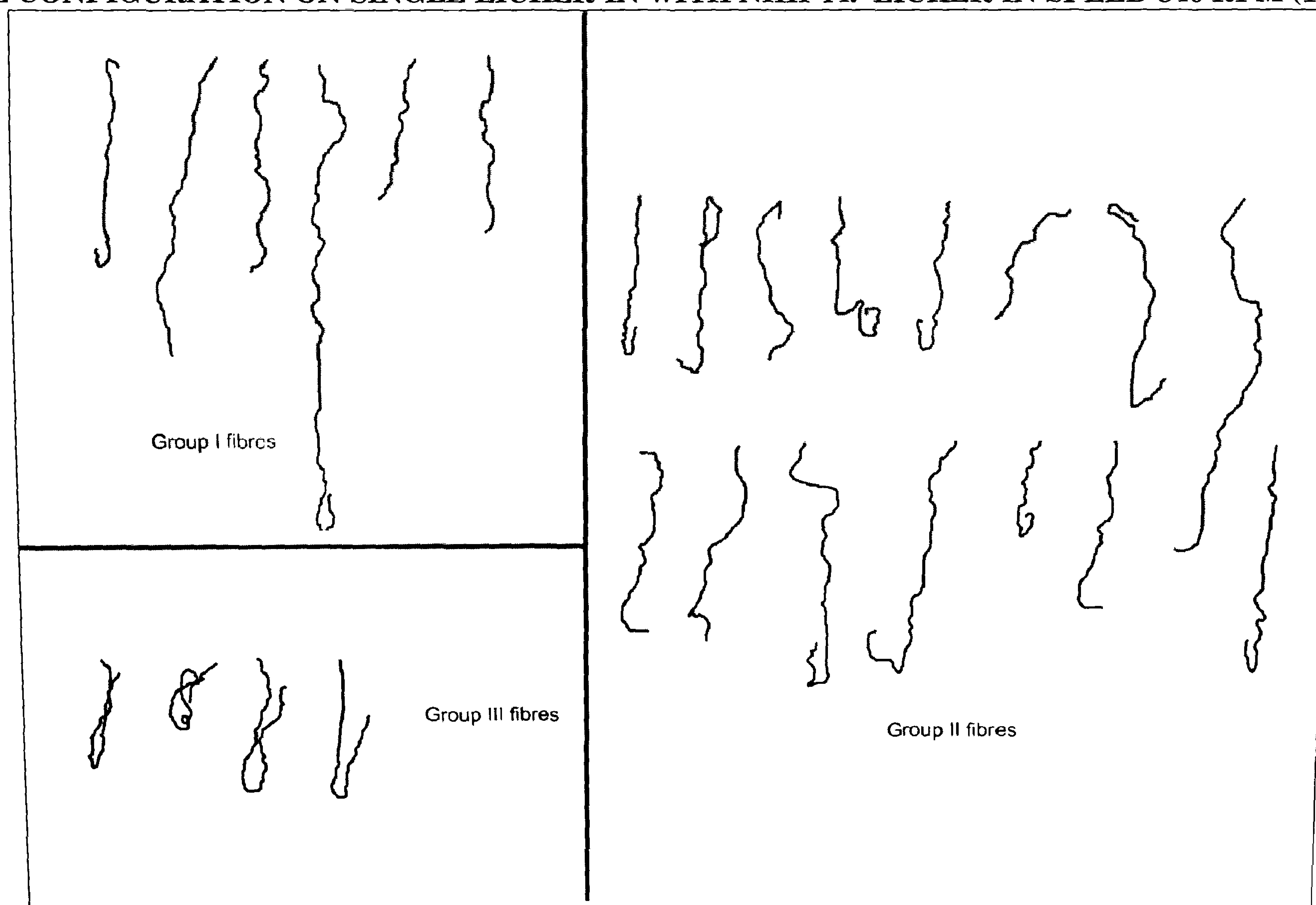
APPENDIX 39

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH DCH 32: PRODUCTION 20 kg/hr



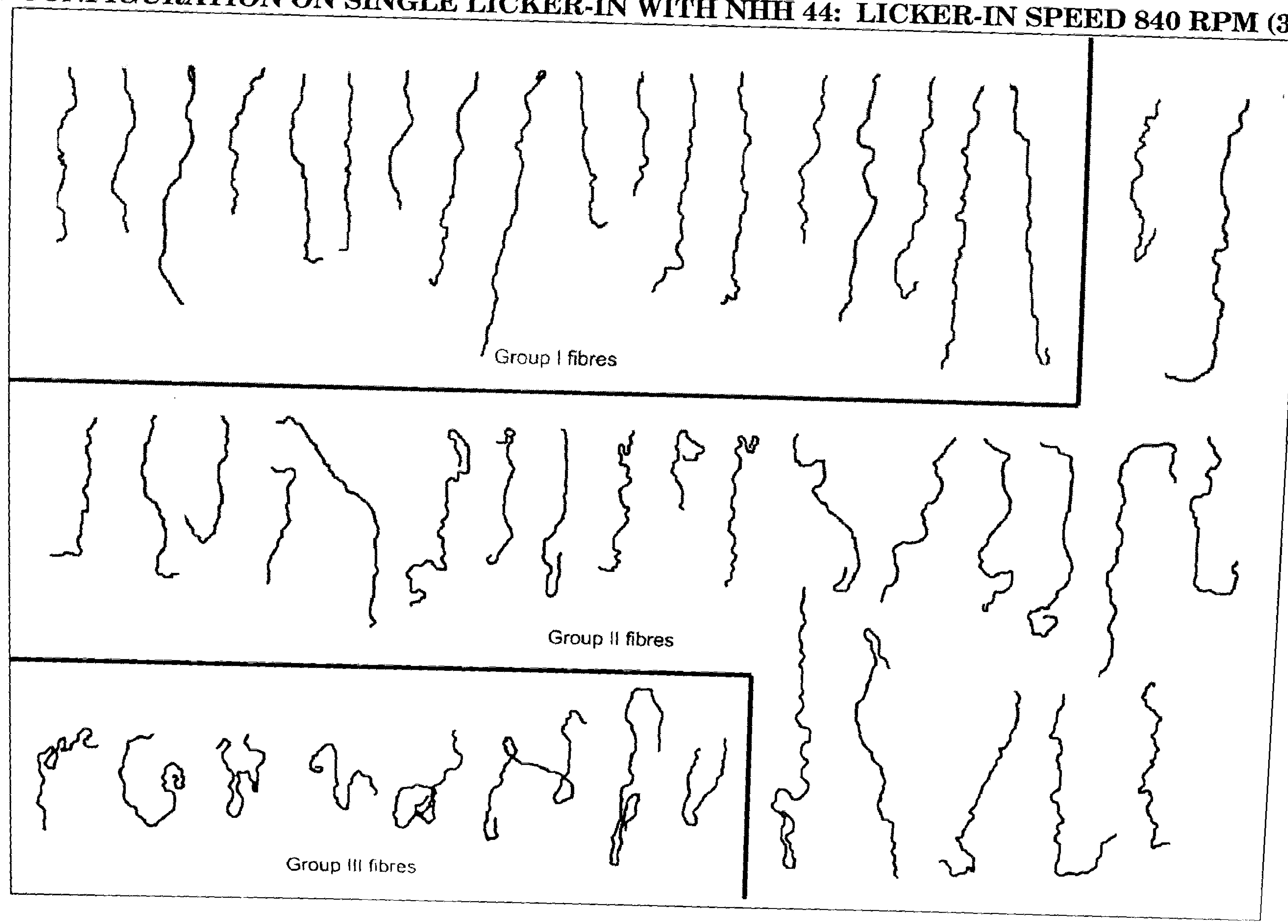
APPENDIX 40

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH NHH 44: LICKER-IN SPEED 840 RPM (10 kg/hr)



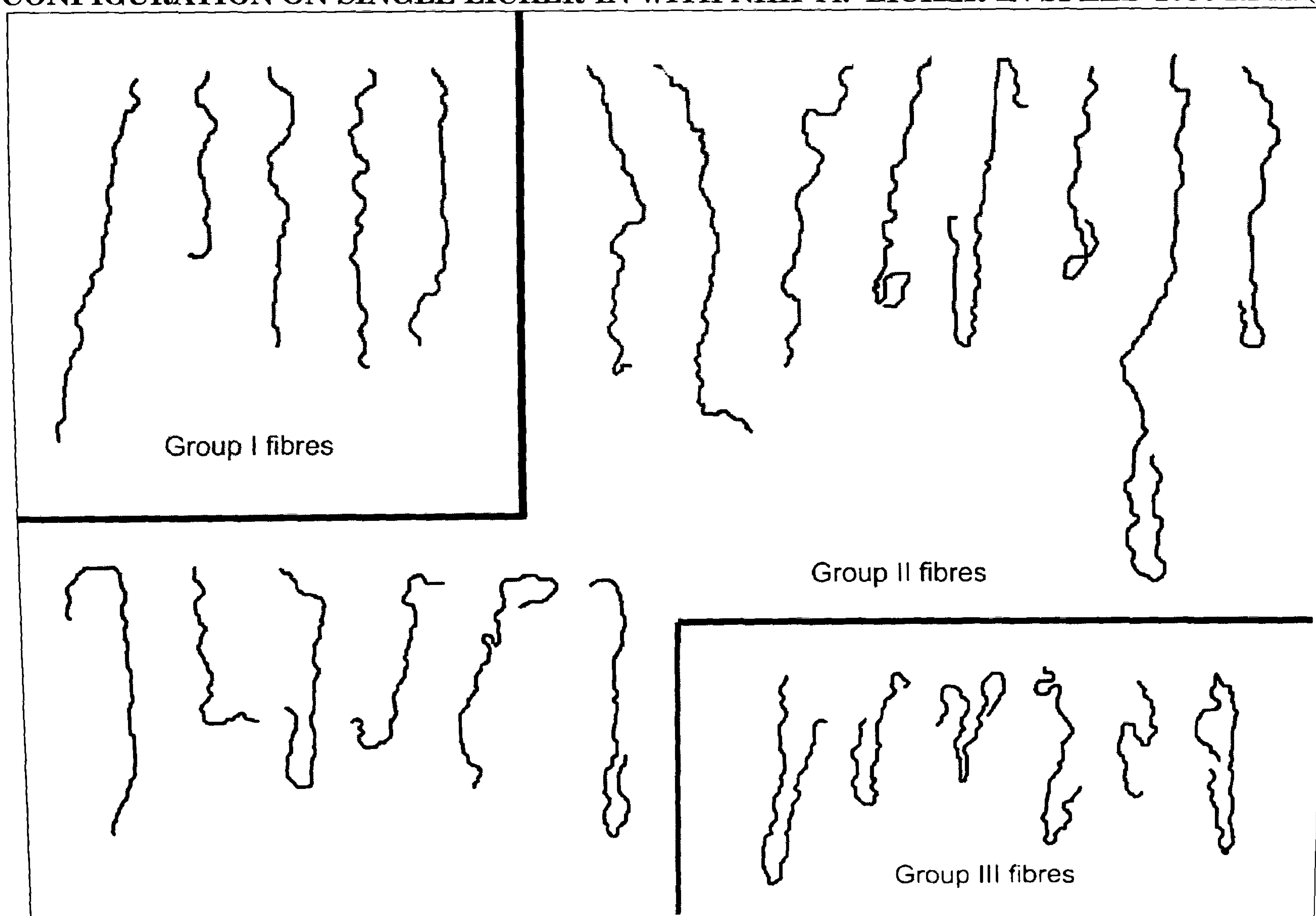
APPENDIX 41

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH NHH 44: LICKER-IN SPEED 840 RPM (30 kg/hr)



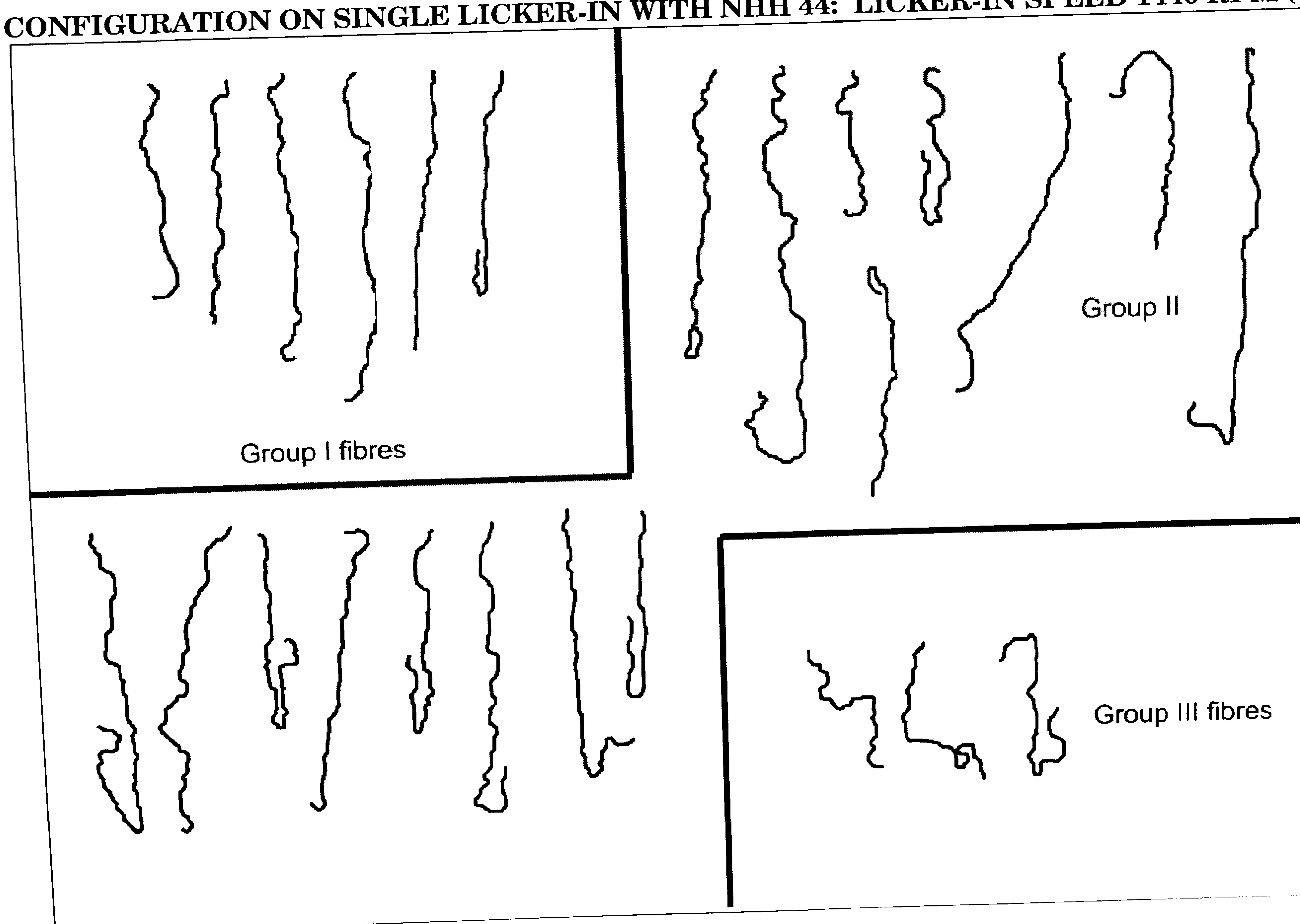
APPENDIX 42

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH NHH 44: LICKER-IN SPEED 1080 RPM (30 kg/hr)



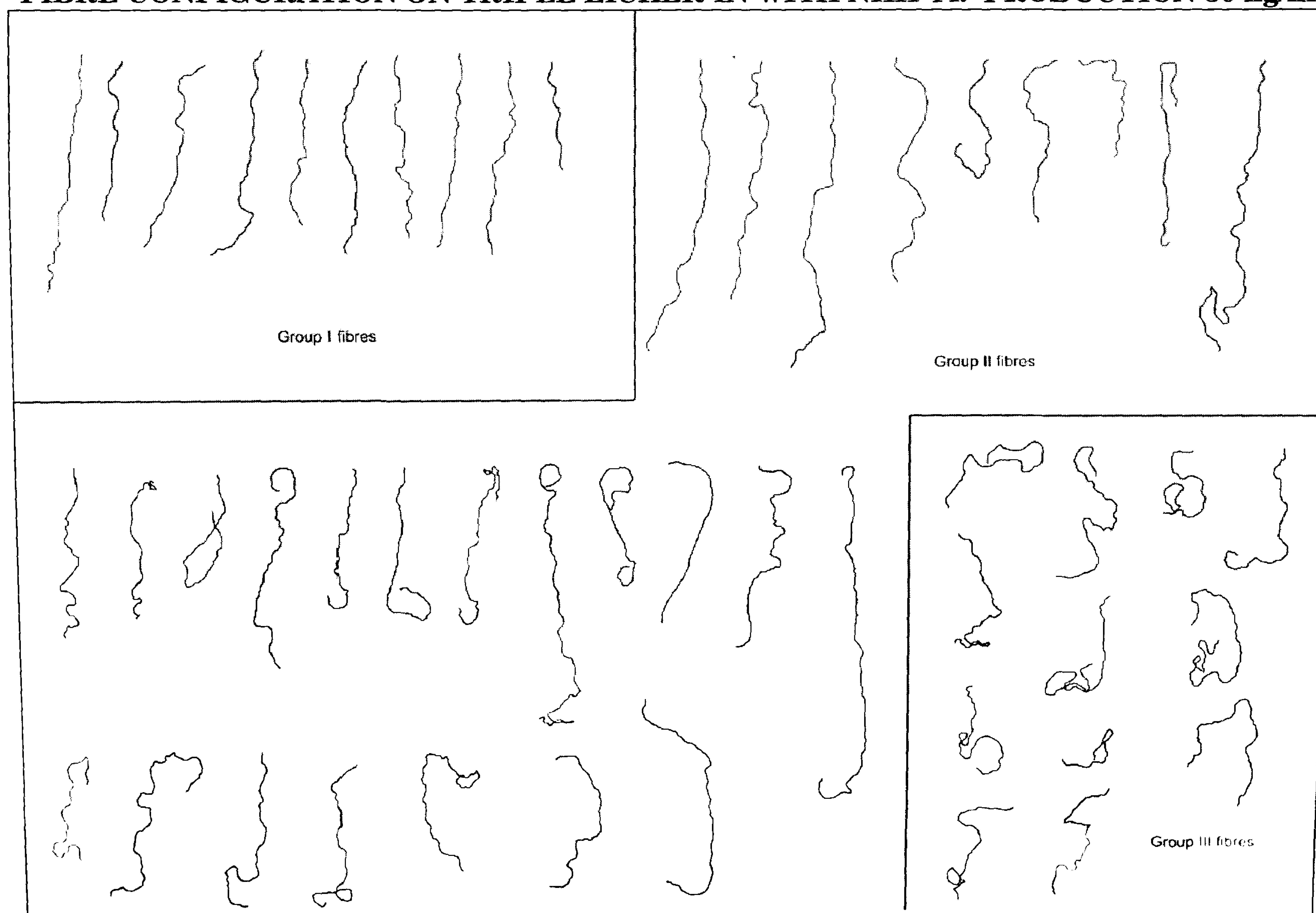
APPENDIX 43

FIBRE CONFIGURATION ON SINGLE LICKER-IN WITH NHH 44: LICKER-IN SPEED 1440 RPM (30 kg/hr)



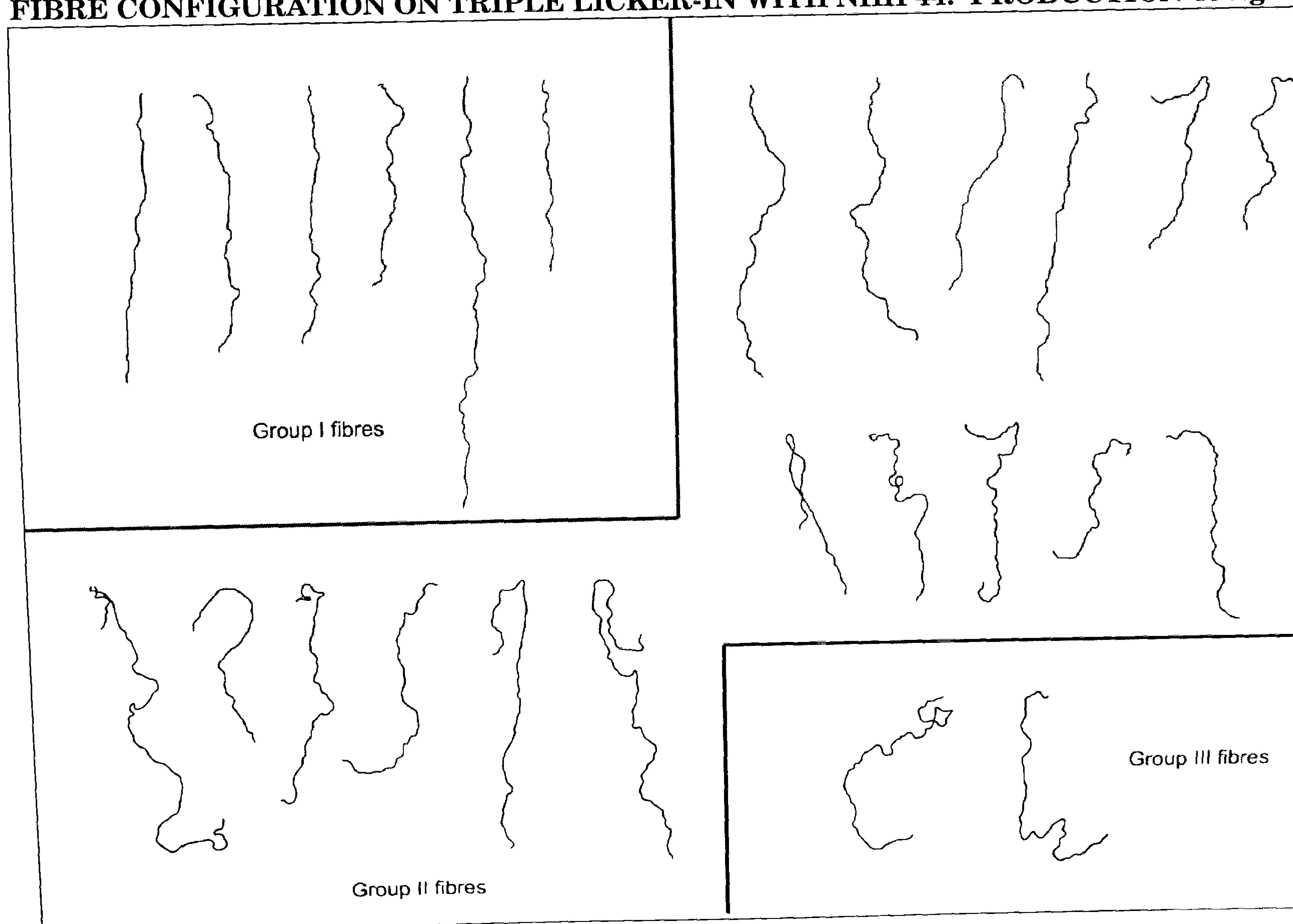
APPENDIX 44

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH NHH 44: PRODUCTION 30 kg/hr



APPENDIX 45

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH NHH 44: PRODUCTION 45 kg/hr



APPENDIX 46

FIBRE CONFIGURATION ON TRIPLE LICKER-IN WITH NHH 44: PRODUCTION 60 kg/hr