TECHNICAL BULLETIN

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TRI 1004

INTRODUCTION TO OPEN-END SPINNING

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INTRODUCTION TO OPEN-END SPINNING

The purpose of this bulletin is to explain and describe how open-end yarns are spun.

A staple yarn may be defined as a continuous collection of fibers held together by a binding medium such as twist.

Since before 1900, ring spinning has been and still is the method used to produce most of the world's yarn. It is only logical, then, that open-end spinning will be gauged by its performance in direct competition with the older, proven, and accepted system. For this reason, we will review the basic principles of ring spinning before proceeding with a description of open-end spinning.

Ring Spinning

The basic requirements and functions of a ring-spinning frame are:

a) fiber supply,
b) drafting,
c) twisting, and
d) package winding.

The fiber supply, usually in the form of roving and having a hank* range from approximately 0.40 to 5.0, is drawn into the drafting system by the rotation of the back rolls. In the drafting zone, the weight per unit length of the input roving is reduced because the surface speed of the front drafting rolls is greater than that of the back rolls. Normal ring frame drafts range up to about 30.

The front rolls deliver a continuous cohesive stream of fibers, which must be twisted immediately into yarn. This transformation is accomplished by the interactions of the spindle, ring and traveler (shown in Exhibit 2). The rotation of the spindle causes twist to be inserted into the stream of fibers delivered by the front rolls. By passing the yarn under the traveler, winding is accomplished.

The spindle serves three functions: first, it provides a location to wind a package; secondly, by rotating the yarn package, the spindle causes twist to be inserted into the strand of yarn being formed at the nip of the front rolls; thirdly, the rotation of the package causes the yarn to pull the traveler around the ring, providing a method of not only transmitting twist derived from the spindle, but also a guide to change the direction of yarn travel so that it approaches the yarn package tangentially, and thus can be wound onto the package.

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*The English system of numbering yarns is explained in Exhibit 1.

Limitations: Mechanically speaking, the production of a ring frame is limited by excesses in one or more of the following:

a) spindle speed,
b) front roll speed,
c) traveler speed,
d) frame down-time for doffing.

Economical limitations on ring spinning are related to power consumption and package size. Power requirements to rotate the package are greater than that needed to insert twist only. The package size is limited since it must be enclosed in the yarn balloon. Finally, for very coarse yarn counts, frame down-time for doffing must be considered since it increases as coarser yarns are spun.

Open-End Spinning

The heart of the open-end process is a rotor (see Exhibit 3), wherein fibers can be collected and then drawn off as a yarn. For short staple spinning, most rotors are 31 to 56 millimeters in diameter and may contain a shallow "U" or "V" shaped fiber alignment groove around their periphery. In open-end spinning, the rotor rotation provides the twisting force.

Twist has traditionally been inserted into yarn by rotating the package upon which the yarn is being wound. In the case of open-end spinning, the twisting force is generated by the rotation of a rotor and is transmitted by friction to the fibers that make up the tail of the newly-formed yarn. As this twisting tail comes into contact with other fibers, it collects them. Once this process is started, it is self-sustaining, and yarn can then be drawn out of the rotor continuously. In order to prevent twist from being transmitted throughout the length of the fibers that are available for collection into yarn, it is necessary that these fibers not be in any significant frictional contact with one another. It is from this requirement, that the supply fibers not be in intimate frictional contact, that open-end spinning derives its descriptive name. This lack of contact allows true twist to be inserted into the yarn, and at the same time, prevents twist from being transmitted throughout the fiber supply, which would result in instant stripping of the rotor.

Differences: The basic difference between ring-spun yarns and open-end spun yarns is in the way they are formed. The former produces yarn by inserting twist into a continuous ribbon-like strand of cohesive fibers delivered by the front rolls, while the latter forms yarn from individual fibers directly by collecting them from the inside surface of a rotor by twist forces. Thus, for comparison, it could be said that a ring yarn is formed from the outside in, while open-end yarn is formed from the inside out. This is shown in Exhibit 4.

The elements basic to production of open-end yarns are somewhat different from ring spinning (Exhibit 5). They are:

a) fiber supply,
b) drafting system,
c) fiber collection and alignment,
d) twist insertion -- yarn formation, and
e) package winding.

The fiber supply used by all open-end machinery is in the form of sliver, either directly from the card or from the draw frame. This being the case, it is evident that the roving process long associated with ring spinning is no longer needed.

When this fact is considered, it becomes apparent that the total draft for a given yarn produced on an open-end machine will be greater than that of a ring frame producing the same yarn. For instance, the draft of an open-end frame producing 24/1 from 60 grain sliver would be 172.8, while the draft on a ring frame producing the same 24/1 yarn from 0.80 hank roving would be 30.

Thus, the overall draft of an open-end frame is likely to be quite high; as a result, open-end equipment manufacturers decided to abandon roller drafting as being too cumbersome to use to develop the high drafts required for rotor spinning.

In place of roller drafting, a simple wire or pin-covered cylinder several inches in diameter and about an inch wide is used (Exhibit 6). This beater, or combing roll, as it is normally referred to, works just like a card lickerin; it is, in fact, covered with metallic card wire, or possibly steel pins.

The rotational speed of a combing roll ranges from about 3,000 to 10,000 rpm with 4,000 to 8,000 being most common.

In actual operation, the supply sliver is presented to the rotating teeth of the combing roll by action of a feed roll/feed plate mechanism. When the position is started, a brake is released that allows the feed roll to pull sliver between itself and the feed plate, and thus present a beard of fibers to the combing roll. (See Exhibit 7.)

There is a very high draft between the feed roll/feed plate and the rotor. This draft normally will vary in a range from 1,000 to 40,000 or higher, depending on the count produced, draft, and required twist. This high draft delivers individual fibers and/or small individual fiber groups to the rotor where they are deposited randomly around the inside of the rotor over a period of many revolutions. This deposited fiber mass has very little fiber-to-fiber cohesiveness, and it is this fact that makes open-end spinning possible.

The combing roll combs out fibers and carries them to the fiber transport duct that connects the combing roll chamber to the rotor chamber. (See Exhibit 7.) A combination of centrifugal force and air suction from the rotor chamber tends to strip the fibers away from the combing roll and send them into the fiber transport duct.

The fiber transport duct is aimed tangetically at the rotor's fiber alignment groove. This duct exit usually is located very close to the groove to prevent newly-arrived fibers from being collected by the newly-formed yarn before ever reaching the rotor alignment groove. Some manufacturers choose to align the fiber delivery tube so that fibers entering the rotor first contact the rotor wall just above the fiber groove, and then slide down the wall into the groove. These manufacturers believe that better fiber alignment is obtained using this method. Other machinery manufacturers do not use the fiber delivery duct to direct the fibers into the rotor groove, but rather use a separator plate to direct newly-arrived fibers into the fiber alignment groove.

Some machinery builders have designed a trash extraction feature into their combing roll drafting systems. This feature is illustrated in Exhibit 8. The system is designed so as to allow the lighter fibers to be carried by air currents and the combing roll teeth safely across the port while the heavy trash particles, by reason of their mass, will deflect through the opening and out of the system.

Open-End Yarn Formation: In rotor spinning, the yarn is formed inside the rotating rotor from a continuous stream of individual fibers arriving from the combing roll. This spinning action can be explained as follows. Please refer to Exhibit 9, which is a schematic diagram of the inside of a rotor.

Ring "A" represents the inside groove of the rotor where the fibers are collected.
Ring "A" rotates in the direction of Arrow "a" at a fixed rate.

Newly formed yarn is seen at "B" and moves in the direction of Arrow "b" to the yarn withdrawal tube "T" where it is drawn out of the rotor and wound onto a cheese.

The new yarn is actually formed in Area "C" by twist collection of individual fibers. This area is known as the fiber binding zone.

The point where the fibers leave the rotor surface is called the "peeling point" and is identified as Point "P."

The peeling point advances in the same direction as the rotation of the rotor, shown by Arrow "a." The rate of advance of this point is determined by the turns per inch of twist being inserted into the yarn.

One turn of twist is theoretically inserted into the yarn each time the rotor makes one complete revolution. This being the case, it becomes obvious that rotor speed and production are directly related.

For example: Rotor speed = 60,000 rpm
Turns per inch required = 30

$$\frac{60{,}000}{30} = 2{,}000 \text{ inches per minute of yarn delivered}$$

On closer examination, we can determine the rate of advance of the peeling point from the above figures. The rpm of the rotor is 60,000 and the inches of yarn to be delivered per minute with 30 turns per inch is 2,000. Therefore, the peeling point must advance at a rate equal to the inches delivered per minute divided by the rotor revolutions per minute, or:

$$\frac{2{,}000}{60{,}000} = .03333 \text{ or approx. } 1/32 \text{ inches}$$

In this example, the peeling point advances 1/32 of an inch per revolution of the rotor.

Given a rotor diameter of 2.0 inches, the inside circumference would be 6.28 inches. For the peeling point to traverse this distance, the rotor would have to make 188.4 revolutions, or:

$\frac{6.28}{.03333}$ = 188.4 revolutions of the rotor required for the peeling point to make one complete circuit of the inside surface of the rotor.

As a matter of fact, this relationship between the rotor circumference and the rate of advance of the peeling point is referred to as "doubling factor." The effect of the doubling factor is to suppress roller drafting waves normally associated with ring-spun yarns. This is accomplished because the fibers are deposited inside the rotor over a period of many revolutions, and thus lose any semblance of their original order. Naturally, any changes in the weight per unit length of the input sliver are also greatly diminished by the doubling effect.

It should also be noted that the doubling factor has the greatest influence on reducing those wave lengths which are shorter than the rotor circumference (πD). At wave lengths longer than πD, various errors within the rotor begin to manifest themselves, and any gains in evenness beyond πD attributable to the doubling factor tend to be covered up. This leads to the conclusion that poor fiber preparation in the processes preceding spinning cannot be offset by the doubling effect since their wave lengths will exceed πD. Since there is a direct relationship between yarn delivery speed and the TPI (Turns per Inch), it follows that the magnitude of the doubling factor and its effect on yarn quality decrease as fewer turns per inch are inserted into the yarn. Thus, the effect of the doubling factor on coarse yarns will be substantially less than it will be on finer counts.

General Cotton Fiber Considerations for Successful Open-End Spinning: Cotton is a very unique natural fiber, possessing a wide variety of properties that make the fiber universally useful. Over the years, ring spinners have determined which cotton properties must be controlled to enable them to efficiently produce quality yarns. These properties are length, length uniformity, strength, micronaire and non-lint content.

These same properties are of paramount importance to open-end spinning also, but the order of importance varies considerably. Based on available data, the probable order of property importance for open-end spinning is as follows:

a) non-lint content,
b) strength,
c) micronaire,
d) length,
e) length uniformity.

The basic importance of each of these properties to open-end spinning follows:

Non-Lint Content: The non-lint content of the input sliver has a profound effect on both yarn quality and machine performance. Any non-lint particles that enter the rotor suspended in the fiber transport air are subject to centrifugal forces generated by the rotation of the rotor and sufficient to cause these particles to deposit on the inside surfaces of the rotor. Once deposited, there are only two ways these particles can be removed: (1) to be picked up by the yarn and carried out, and (2) to stop the rotor and clean it by hand.

The deposition of particles can be of either a uniform nature, which affects overall yarn quality and strength by filling up the fiber alignment groove, or it can be concentrated in one spot, caused perhaps by the jamming of a relatively large particle into the alignment groove. This type of loading problem will certainly result in a periodic defect in the yarn and very likely an end down.

The standard methods of measuring non-lint content are:

a) Shirley Analyzer
b) Shirley Trash Separator
c) ITV Dust and Trash Tester (MDTA3)
d) Microdust and Trash Monitor (MTM)
e) Uster AFIS Module T

As determined by any of these methods, non-lint content of input sliver to be processed on self-pumped open-end machines probably should not exceed 0.10% for best performance. For separately pumped open-end machines with combing roll cleaning ports, the non-lint content of the input sliver should be no greater than 0.25% for best performance. However, machines with built-in cleaning can tolerate levels in excess of 0.25% non-lint with some loss in machine efficiency and increased maintenance costs.

There are two reasons why the separately pumped machines can tolerate a higher non-lint content. The first is, of course, the incorporation of a cleaning port under the combing roll that functions like a fiber retriever under a card. The fibers are carried over the opening by virtue of their length and velocity while the heavy trash particles tend to deflect away from the fiber path and through the cleaning port.

The second reason is that since the rotor itself does not generate the air flow required to transport the fibers from the combing roll to the rotor, the path of the air flow is across the face of the rotor rather than through it. Thus, an alternate path is offered to fine dust particles and this results in an additional *reduction*, but *not* an *elimination*, of the non-lint deposition problem. The importance of controlling non-lint content cannot be overemphasized.

Micronaire: The weight or fineness of a cotton fiber is related to its surface area. The greater the surface area, the coarser the fiber. (Micronaire is defined as the average weight of one-inch lengths of fiber expressed in micrograms.)

To successfully spin yarn, a certain number of fibers are needed in the yarn cross-section. In other words, a certain minimum number of fibers must be delivered per unit length of a given yarn or else the ends down will be excessive. This number is not precisely fixed since it is influenced by factors such as fiber length, strength, and twist multiple. However, it is generally accepted that ring spinning requires a minimum of 60 to 80 fibers in the cross-section. 100 fibers per yarn cross-section was the accepted minimum on rotor spinning until recent years when advancements in machine design made possible numbers less than 100.

Therefore, from an efficient operating point of view, it should be clearly understood that in finer counts, open-end yarns are much closer to the critical red line requirements for minimum fibers in the cross-section than would be the case if the given yarn was being ring spun. This is graphically shown in Exhibit 10.

The reverse is true for very coarse counts. In other words, more fibers may be required than can pass by the combing roll and through the fiber transport duct to the rotor. For every open-end spinning system, there is a maximum number of fibers that can pass through the fiber transport duct without choking the opening.

Generally speaking then, it should be appreciated that it is possible to spin finer counts or use a lower twist multiple by using finer mic cotton than is normally used in ring spinning. When using low mic cotton, neps can be controlled by using cotton with a high degree of maturity and by selecting the correct card wire.

Strength: There is a significant relationship between fiber strength and resultant yarn strength. Our tests have proven time and again that if a stronger open-end yarn is required, cottons with a higher strength should be utilized. This is graphically shown in Exhibit 10A.

Length: For any given rotor diameter, there is an optimum staple length for best strength, and although the use of longer staples will result in higher strength, it will do so at a rapidly diminishing rate. This is due mainly to the fact that as staple lengths increase, the opportunity for bridging fibers to occur increases. A bridging fiber by definition is one that spans the space on the inside surface of the rotor between the yarn formation or peeling point and the body of newly deposited fibers just behind it. The percentage of bridging fibers may be roughly calculated by dividing the staple length by the inside circumference of the rotor and multiplying by 100 to give percentage. Therefore, although staple length definitely has an effect on yarn strength, it tends to be greatly minimized by the open-end spinning process.

Exhibit 11 shows graphically how a bridging fiber occurs in the rotor.

Open-end spinning is ideally suited for spinning of short fibers. A ring-frame drafting system has a minimum staple length requirement for proper fiber control to produce a quality yarn. Once control is lost, the resultant yarn spins inefficiently, and the yarn appearance is poor. Since open-end yarn is formed by twist attraction of the rapidly rotating open-end, fiber control is no problem and, therefore, short staple fiber can be spun into more even and, in some cases, stronger yarn.

It is interesting to note that as staple length increases, open-end yarn becomes progressively weaker when compared to the same fiber spun into ring yarn. This differential may be as great as 25% to 30% on staples longer than 1-1/8". However, as the staple gets shorter, this differential decreases rapidly and, on some coarser yarns, the open-end yarn might even be slightly stronger. The above assumes comparisons of fiber properties on the same diameter rotor -- as new rotor configurations and sizes are studied, some change in fiber data/performance characteristics can be expected.

Even though fiber length ranks fourth on the rotor spinning list, it is still very important, especially when spinning fine counts. Exhibit 11A shows that when the staple length of a fiber is increased from 1" to 1-3/16", very little strength is added to the coarser yarn counts. On the other hand, the strength of the fine yarn counts increases considerably.

Length Uniformity: Length uniformity has always been considered of prime importance to ring spinning, and for best rotor spinning results, good length uniformity is also important, especially when spinning fine count yarns.

Yarn Properties: The structure of open-end yarn is significantly different from ring-spun yarns. It may be seen from Exhibit 12 that fibers in a strand of open-end yarn are not as parallel as in ring yarn. This is especially true of surface fibers; many are simply wrapped about the strand of yarn randomly. However, the fibers near the center of the yarn are more compact and contain more twist. The end result is a strand of yarn with a high twist, inner core of fibers surrounded by a sheath of wrapper fibers containing must less twist. This difference causes varying distribution of stress across the yarn from the axis to the surface and contributes to the uniqueness of open-end yarn. Some of the important properties of open-end yarn, compared with ring-spun yarn, are given below using the same fiber input into both:

- 10% to 30% weaker,
- higher elongation at break,
- more even,
- better abrasion resistance,
- less hairy,
- less shedding,
- bulkier, and
- larger yarn packages with no knots.

Open-end yarns are usually *weaker* than ring yarns despite the fact that generally higher twist multiples are used in open-end spinning. This is due primarily to a lesser degree of fiber parallelism in open-end yarns. However, this lack of orientation does tend to increase the elongation at break. Open-end yarns are more even than ring yarns due primarily to the suppression of drafting waves by the high doubling factor of fiber layering effect inside the rotor.

The abrasion resistance of open-end yarns is usually better than ring-spun yarns due in part to the higher twist multiples generally used and, to a large degree, to the yarn structure itself; the wrapper fibers carry relatively little load and, therefore, when they are abraded, the strength of the yarn is not seriously affected.

An open-end yarn tends to have fewer hairs extending away from its surface. Whereas ring yarns may have as many as 90% of their fiber ends protruding from the yarn surface, an open-end yarn generally has 25% or less fiber ends protruding from its surface.

The reduction in surface hairs, plus the structure of the yarn itself, generally results in a reduction in the shedding propensities of open-end yarn.

An open-end yarn is usually somewhat larger in diameter than a corresponding ring yarn of the same count. This is due to a lack of parallel orientation of the individual cotton fibers, as is the case in ring-spun yarns. Consequently, open-end yarns are bulkier.

A typical ring-spinning frame produces a package containing such a small amount of yarn that during spooling or winding, many individual bobbins must be combined to produce a full package. To connect one bobbin to the next, it is necessary to knot or air splice the two yarn ends together. As a result, ring yarns may contain knots each 2-4 ounces of yarn. Most mills, however, have air splicer winders to eliminate knot defects. These automatic splicers produce quality yarn joints. Open-end machines produce packages that contain as much as 7 to 12 pounds of knot-free yarn and, as a result, the number of piece ups in open-end yarns is reduced dramatically and a much higher quality yarn results, especially when automatic piecing is used.

In summary, when cottons are selected for open-end spinning, they ideally should have low levels of non-lint, and the fibers should be as mature and strong as possible. The appearance of open-end yarn in fabric (especially knitted) is more uniform and, therefore, desirable for most applications.

EXHIBIT 1

Yarn Numbering System (Linear Density)

All yarn numbering systems are based on one of two basic relationships, namely, weight per unit length (direct) and length per unit weight (indirect). Within each of the two general systems, different yarn numbering units are used based on different standards of unit length or weight. In the direct system, units of denier and tex are commonly used. The indirect system uses units such as English cotton count, worsted count, woolen count, and metric count. In both systems, the basic formula or relationship applies to both hank roving number and yarn number.

The English cotton count unit of the indirect system is more commonly used in the United States, while the metric count is used extensively in Europe. The basic formula for calculating these two units is as follows:

English cotton count (Ne) = hanks/pound =
yards/840 x lbs. =
yards x 7000/840 x grains.

Metric count (Nm) = 1000 meters/kilograms =
meters/gram.

To convert from one unit to the other, the following relationships are used:

Nm = 1.69 Ne; Ne = 0.59 Nm.

In the direct system, the basic formula is:

Denier = grams/9000 meters = grams x 9000 meters.
Tex = grams/1000 meters = grams x 1000/meters.
Tex x 9 = Denier (for conversion).

Quite often, the equivalent yarn number of denier and English cotton count are desired. The relationship between these two units yields the following conversions:

Denier x Ne = 5315
or

$$Ne = \frac{5315}{Denier}$$

or

$$Denier = \frac{5315}{Ne}$$

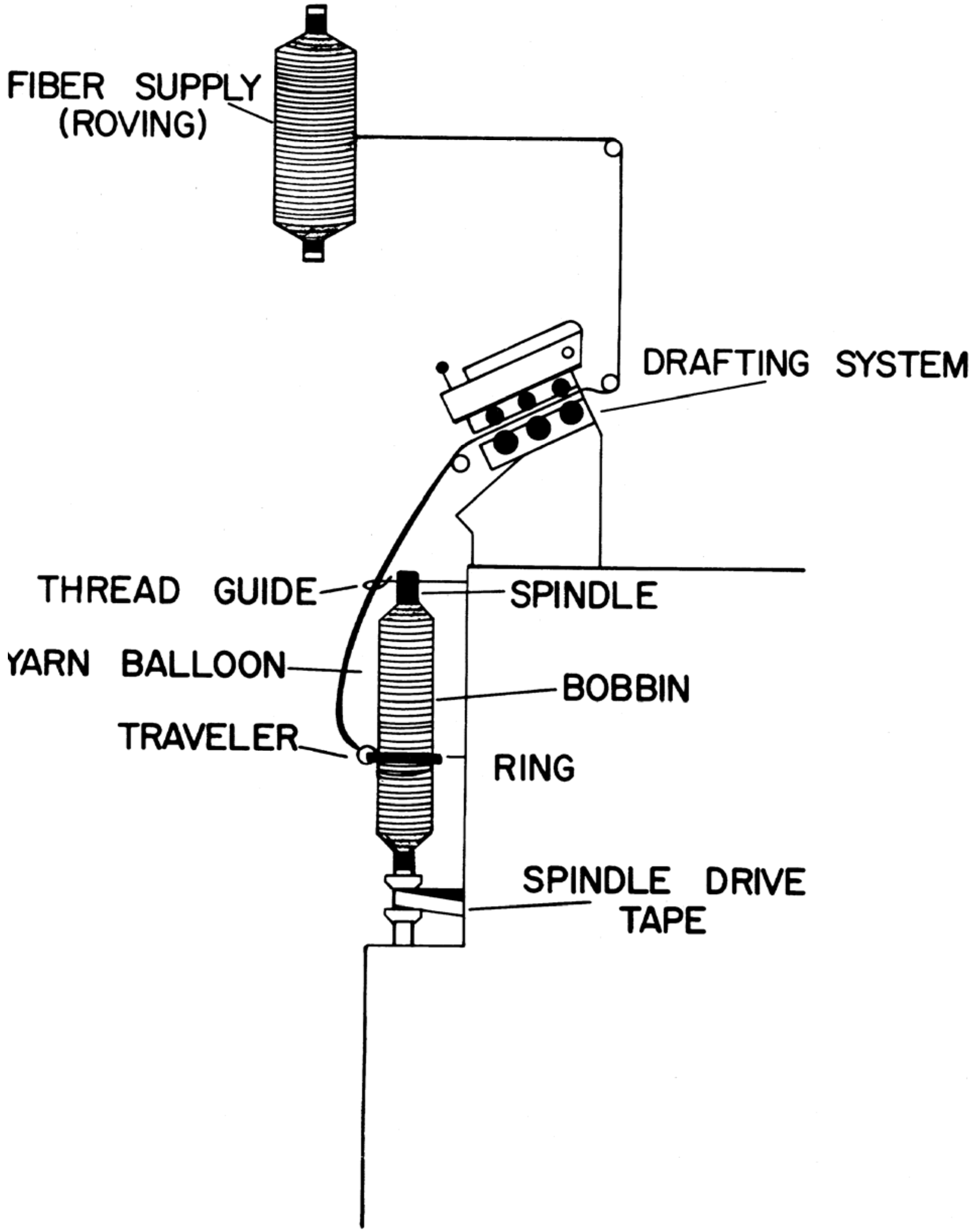

Exhibit 2
Schematic Diagram—Ring Spinning

Exhibit 3
Rotors – Open End Spinning System

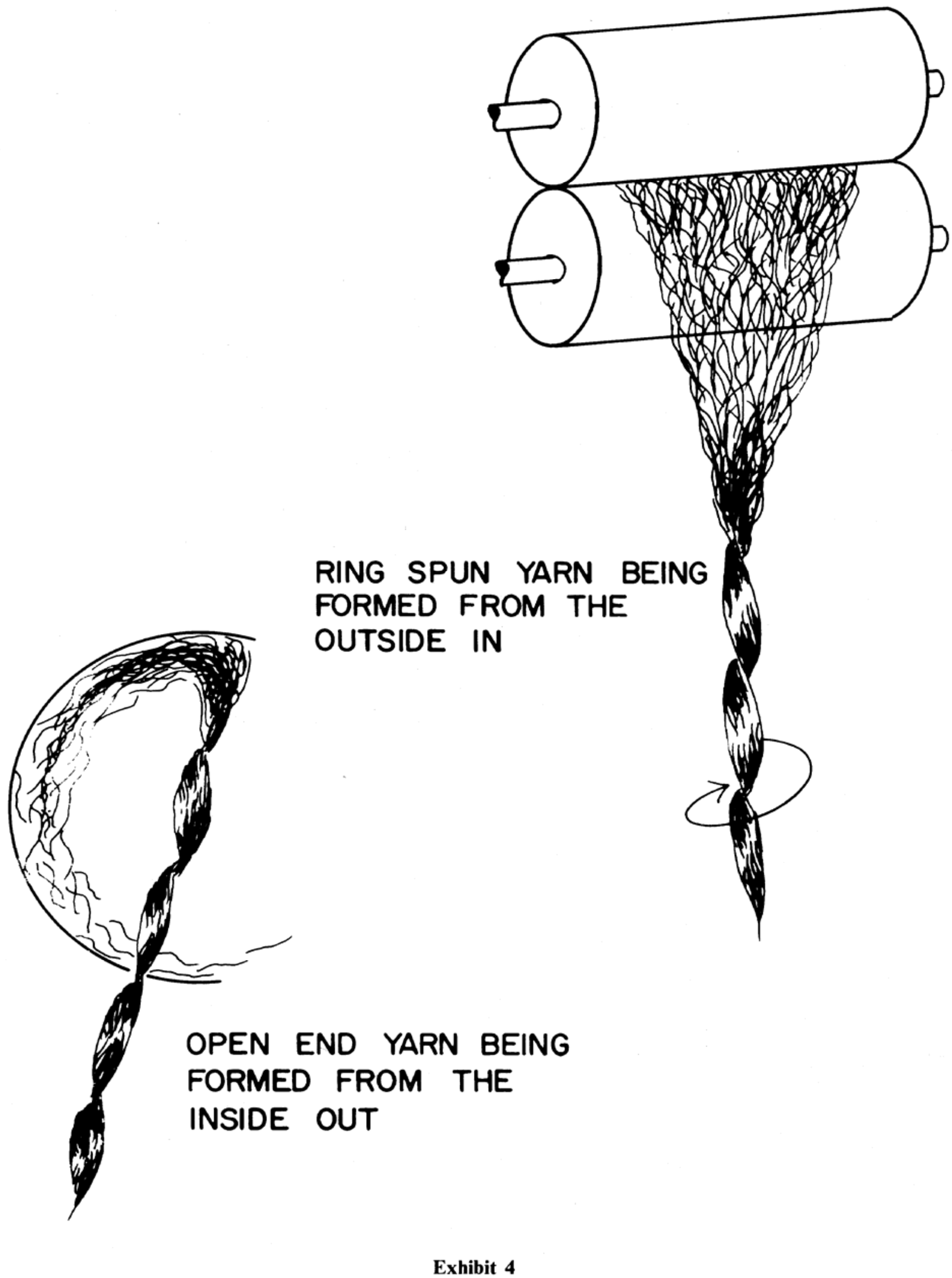

Exhibit 4
Schematic Diagram—Yarn Formation
Ring vs Open End

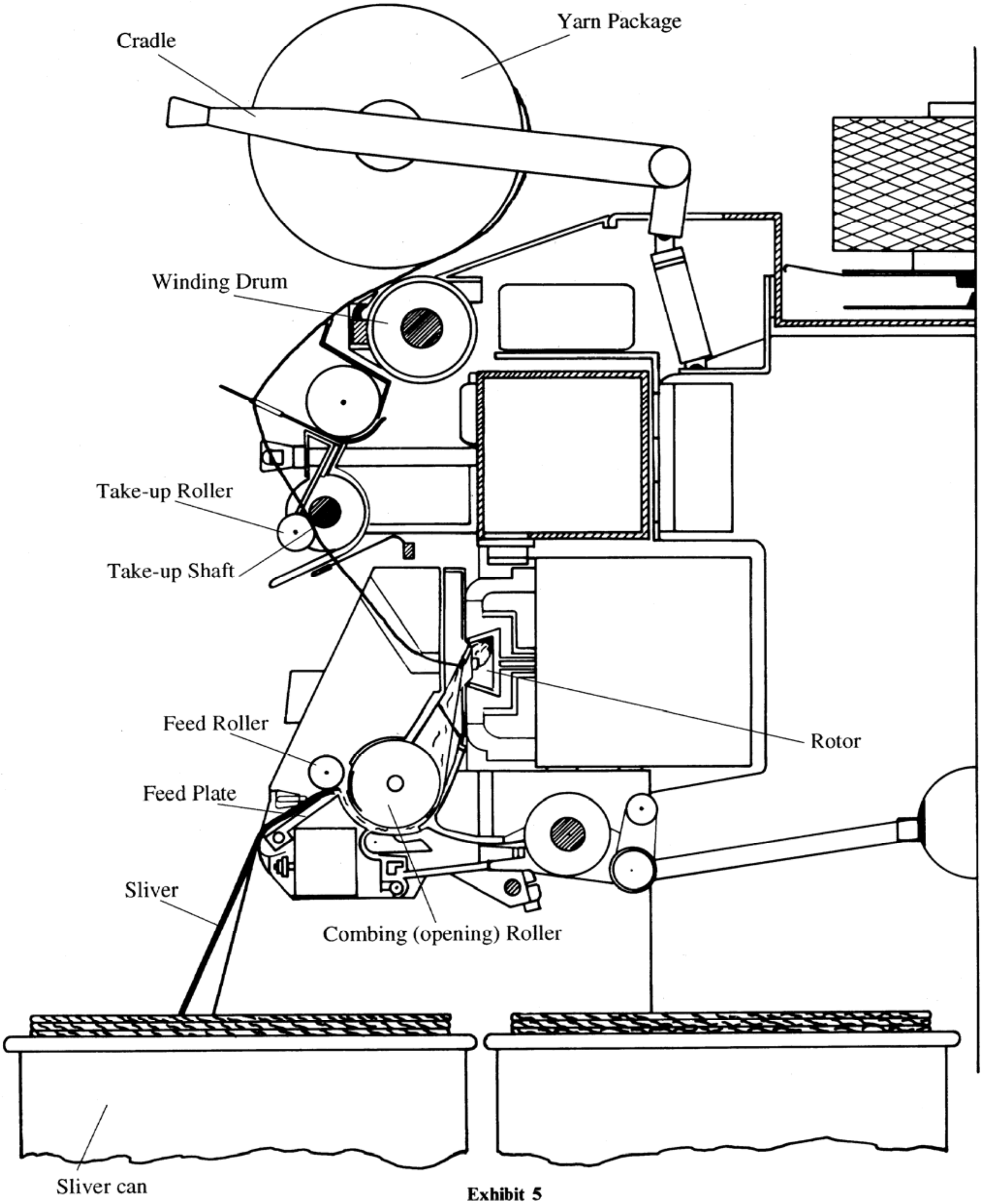

Exhibit 5
Schematic Diagram—Open End Spinning
(Major Elements)

Exhibit 6
Combing Rolls – Open End Spinning

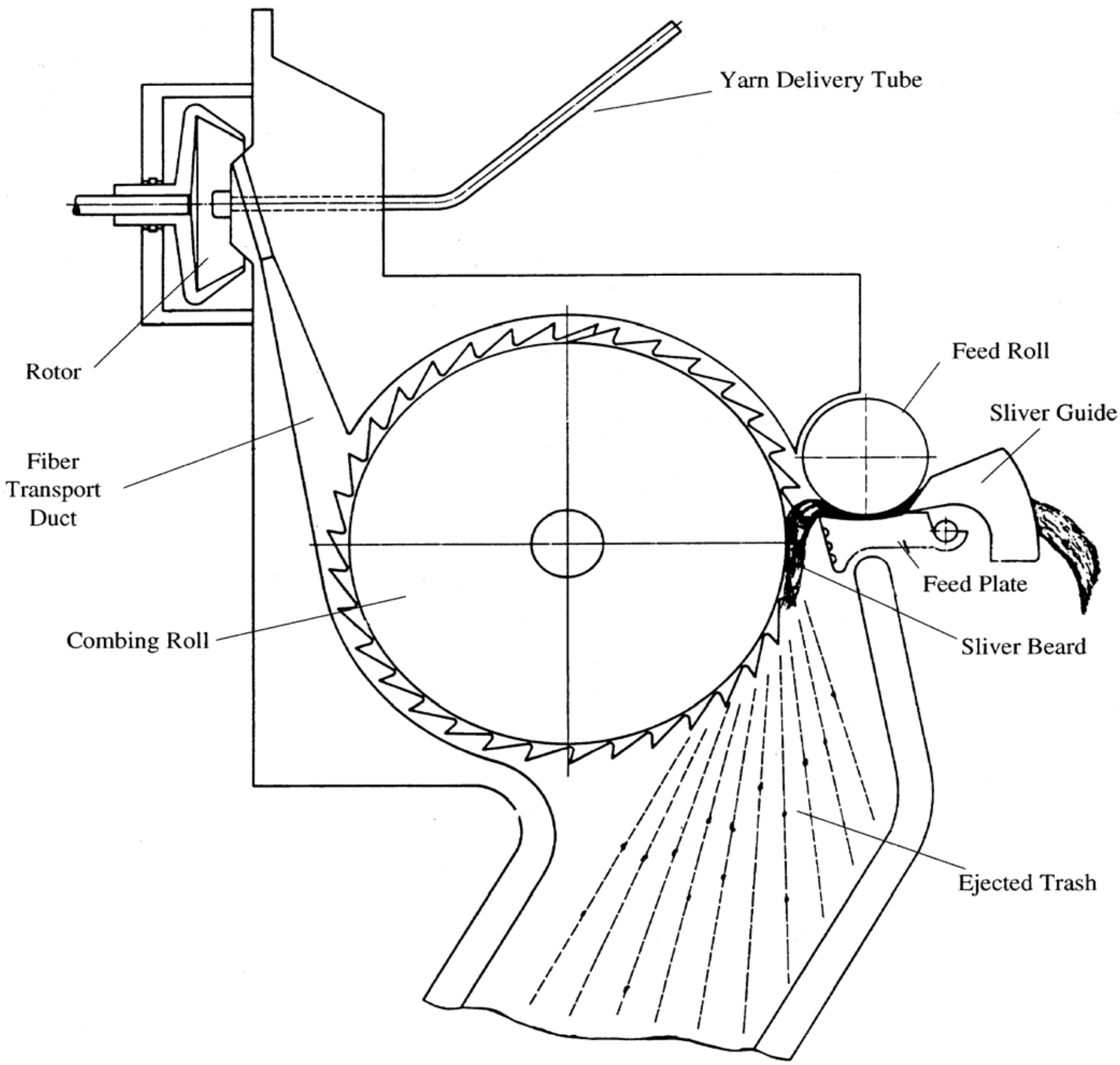
Yarn Delivery Tube
Rotor
Feed Roll
Sliver Guide
Fiber Transport Duct
Feed Plate
Combing Roll
Sliver Beard
Ejected Trash

Exhibit 7

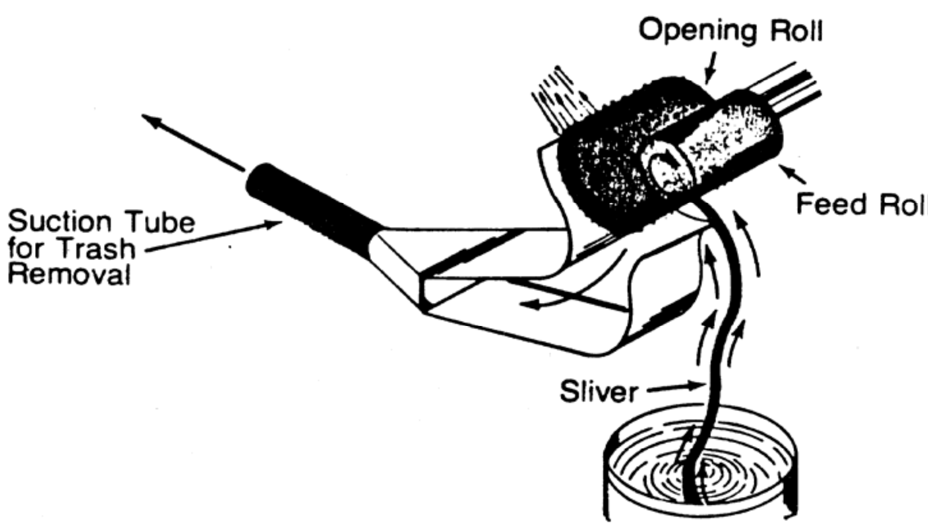

Exhibit 8

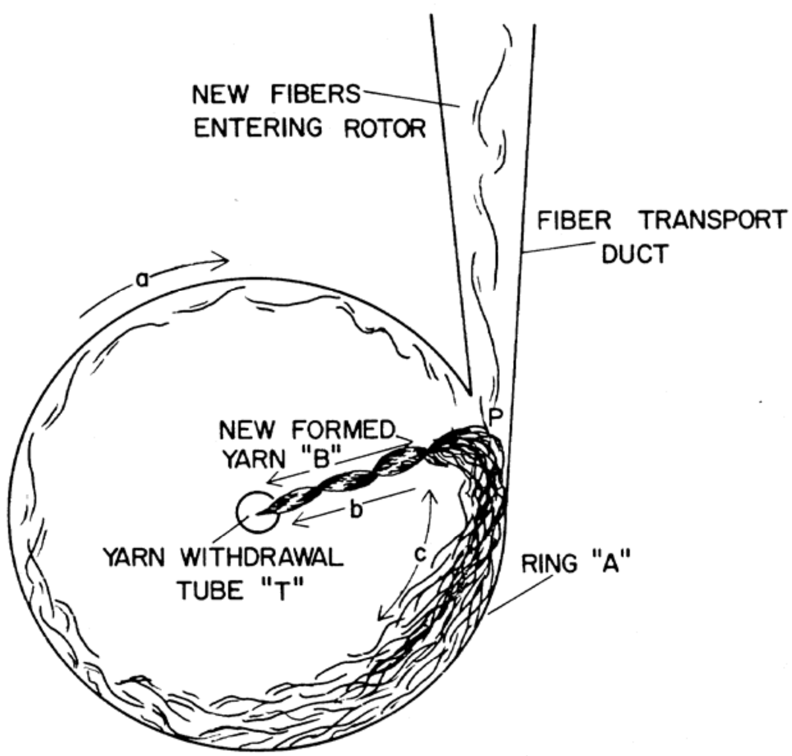

Exhibit 9
Schematic Illustration Showing the Formation of Yarn Inside the Rotor of an Open End Spinning Frame

Spin Limits for Rotor and Ring Yarns

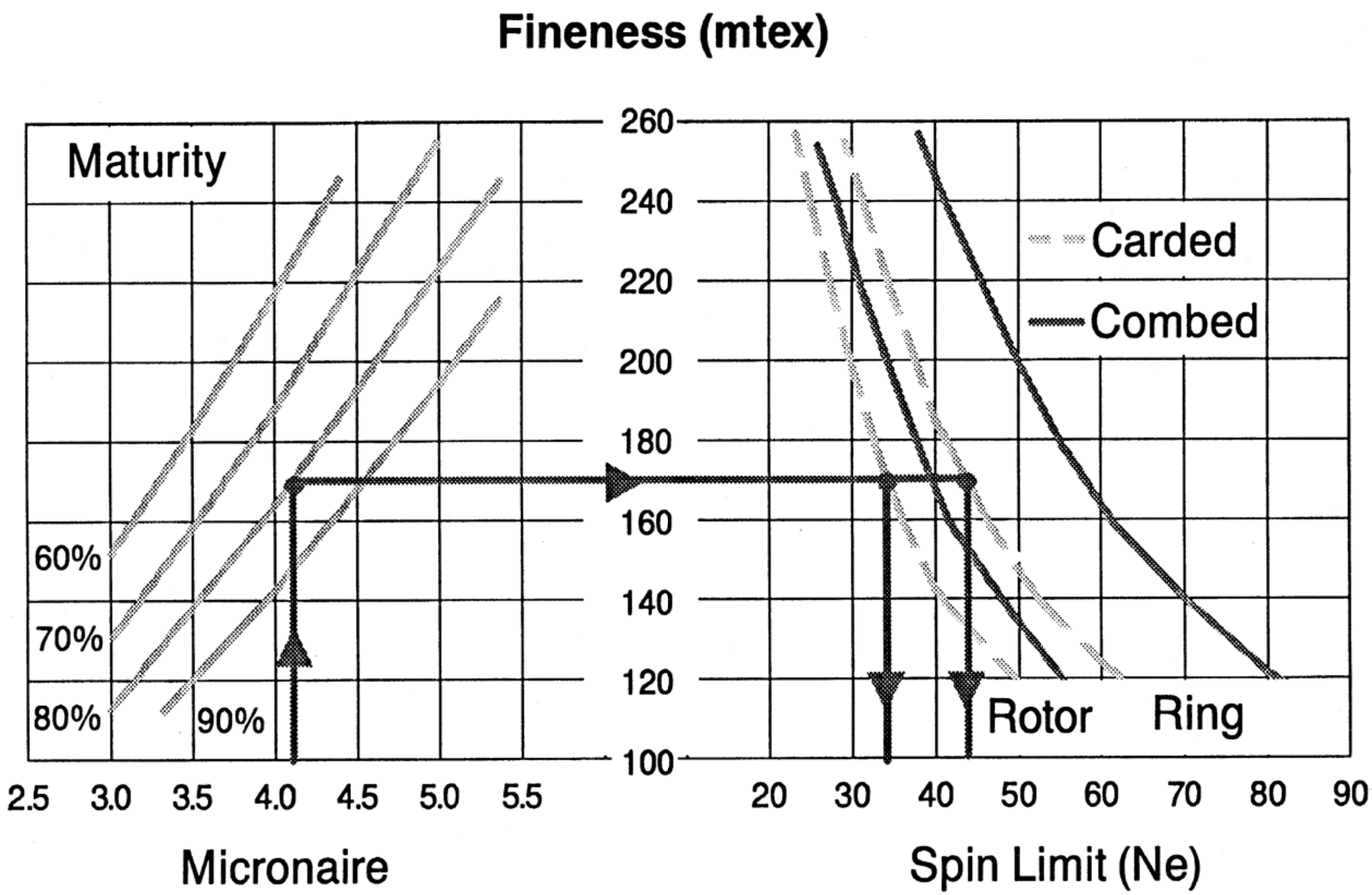

Exhibit 10

Influence of Fiber Tenacity on Yarn Strength

(Yarn: Ne 22 Cotton, 4.8 TM)

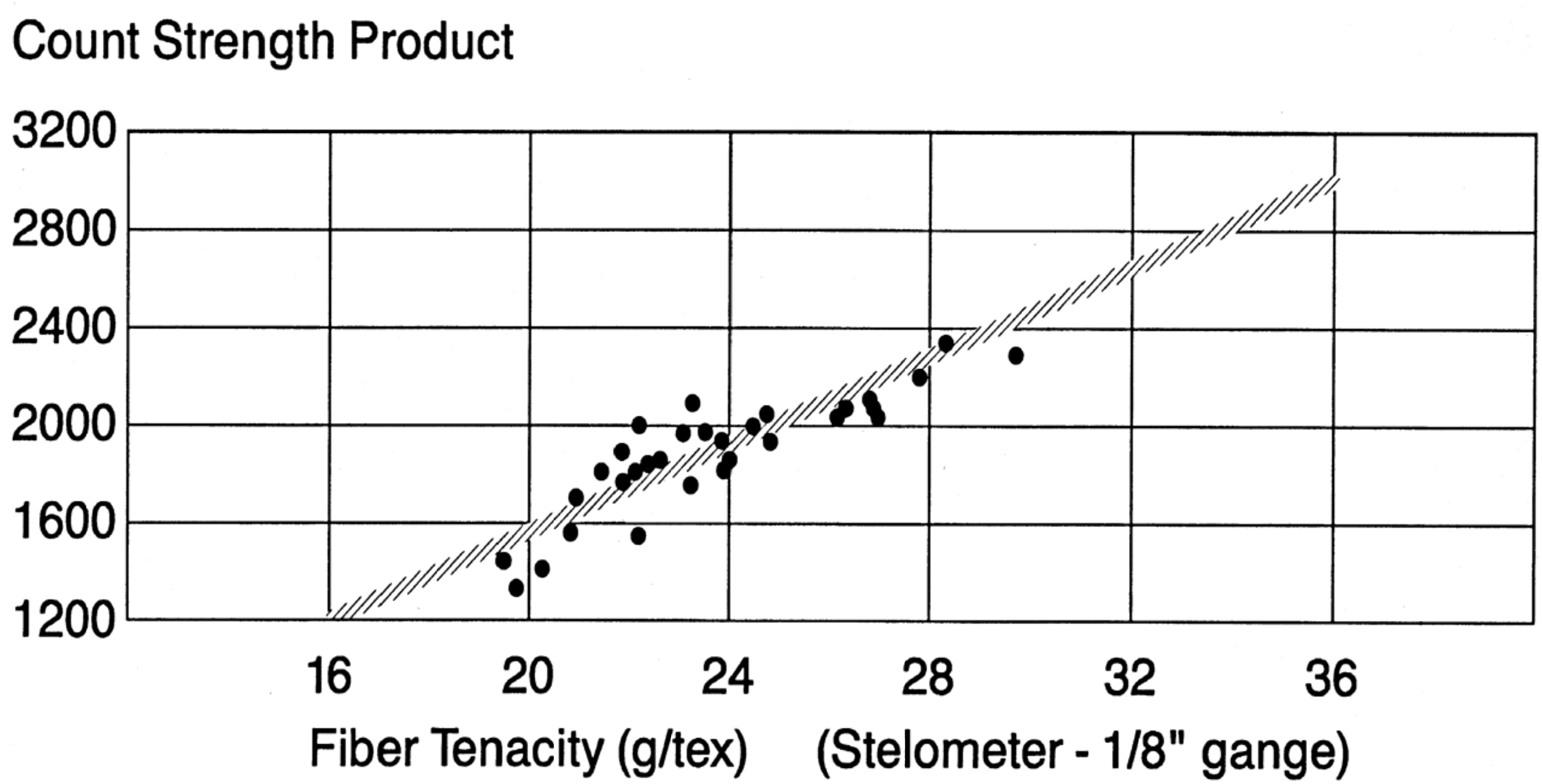

Exhibit 10-A

Courtesy of TRC-Lubbock

BRIDGING FIBERS

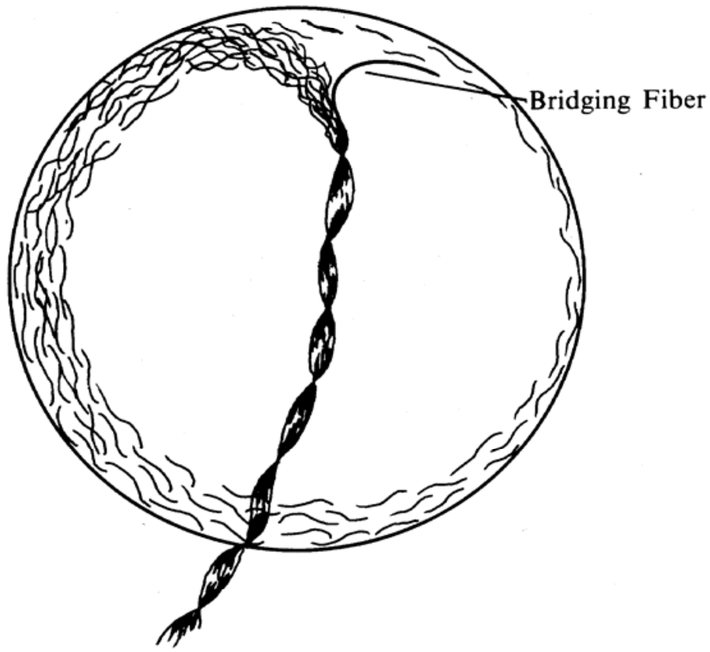

Exhibit 11
Schematic Illustration of the Formation of Bridging or Wrapper Fibers on the Surface of Open End Yarn

Influence of Fibre Length on Rotor Yarn Strength

100% Cotton
TM 4.8
Mic 4.0
28 g/tex

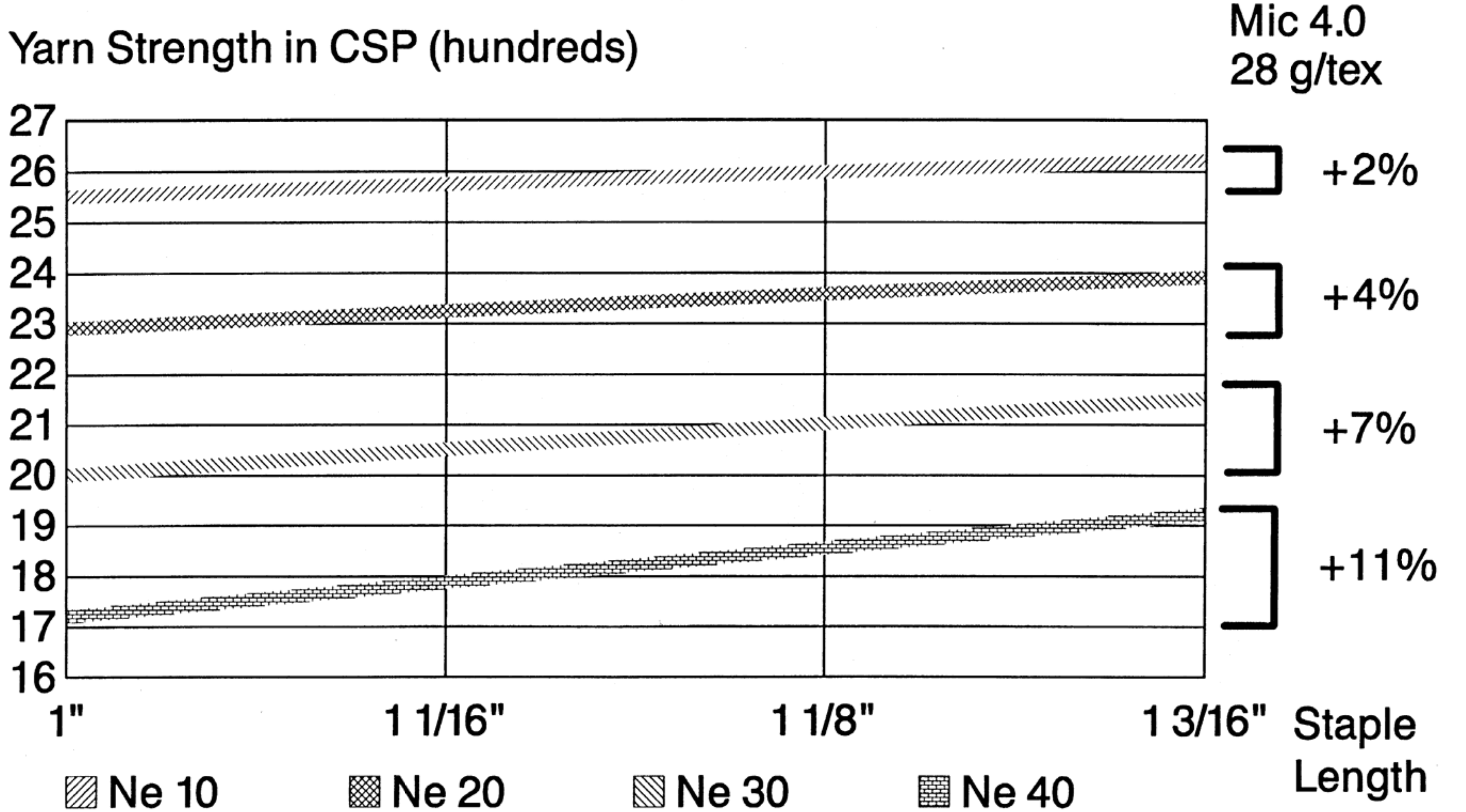

Exhibit 11-A

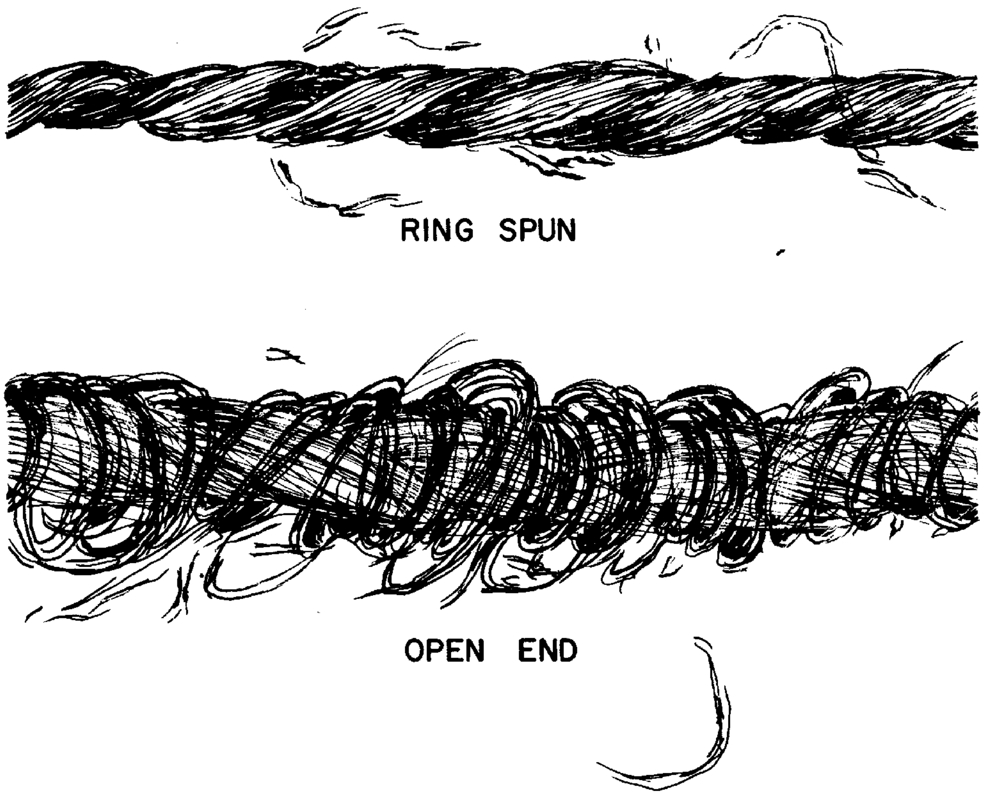

Exhibit 12
Illustration of the Surface Characteristic Differences of Ring and Open End Yarns

RESEARCH AND TECHNICAL SERVICES

Cotton Incorporated is a research and promotion company representing cotton worldwide. Through research and technical services, our company has the capability to develop, evaluate, and then commercialize the latest technology to benefit cotton.

- Agricultural research leads to improved agronomic practices, pest control, and fiber variants with properties required by the most modern textile processes and consumer preferences. Ginning development provides efficient and effective machines for preservation of fiber characteristics. Cottonseed value is enhanced with biotechnology research to improve nutritional qualities and expand the animal food market.

- Research in fiber quality leads to improved fiber testing methodology and seasonal fiber analyses to bring better value both to growers and then mill customers.

- Computerized fiber management techniques result from in-depth fiber processing research.

- Product Development and Implementation operates programs leading to the commercialization of new finishes and improved energy and water conserving dyeing and finishing systems. New cotton fabrics are engineered -- wovens, circular knits, warp knits, and nonwovens -- that meet today's standards for performance.

- Technology Implementation provides comprehensive and customized professional assistance to the cotton industry and its customers -- textile mills and manufacturers.

- A fiber-to-yarn pilot spinning center allows full exploration of alternative methods of producing yarn for various products from cotton with specific fiber profiles.

- The Company operates its own dyeing and finishing laboratory, knitting laboratory, and a laboratory for physical testing of yarn, fabric, and fiber properties including High Volume Instrument testing capable of measuring micronaire, staple length, strength, uniformity, color, and trash content.

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