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The Ideal Rotor Spinning Process for a High Short-Fiber Content

Contents

1. Introduction

Unevenness in staple fiber yarns has been improving constantly in recent decades despite high production speeds at the individual process steps – from fiber preparation through the end-spinning machine (see Fig. 1).

On the one hand, the improvement in unevenness is due to innovations in mechanical engineering, such as optimizations in drafting system design or newly developed technology components. On the other hand, the increasingly precise definition and coordination of raw material, process sequence and yarn count plays an important role.

In recent years, studies have consistently proven that a shorter process – in particular in the rotor spinning process – is not only of interest due to the yarn conversion cost, but can also be appealing for quality reasons. The key criterion here is that the shortened drafting process has a positive effect on cotton with a high short-fiber content.

This study demonstrates what influence the process sequence and the number of draft zones within the drafting system have in the rotor spinning process when using raw material cotton with different short-fiber contents. The impact on yarn quality – such as evenness, tenacity and hairiness – with different yarn counts is also explained in the study.

In addition, the extent to which the technical values of the yarn are reflected in the end product will also be explored. To do this, knitted fabrics were produced using yarns from the different process sequences.

A process recommendation for the rotor spinning system and an evaluation of the economic viability are derived from these findings.

Improvements of Yarn Unevenness Since 1957

100% Cotton, USP™ 50% (Uster Statistics Percentile)

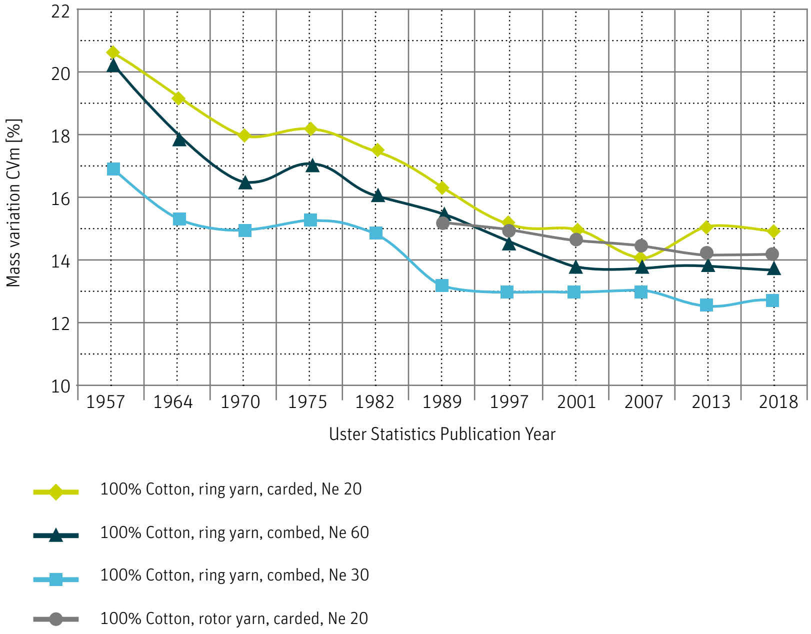


Fig. 1: Unevenness has been improving in recent decades. Source: Uster Statistics

2. Process Shortening for a High Short-Fiber Content

How can the process sequence be optimized for yarn quality? One could presume that a process shortening will result in a lower or at least an unchanged yarn quality. In rotor spinning, however, there are also cases in which process shortening can mean optimization if the raw material has a high short-fiber content.

The higher the short-fiber content, the more positive the effect of reduced drafting system work, as package warping on fiber web is avoided. In addition, a shorter process also reduces conversion costs as fewer machines are used.

The short-fiber content in the raw material is dependent on the following parameters:

- Commercial staple of the relevant raw material origin (see Fig. 2)
- Addition of recyclable raw material waste from the blowroom and card
- Addition of noil from the combing process

Short-Fiber Content versus Commercial Fiber Length

100% Cotton, bale

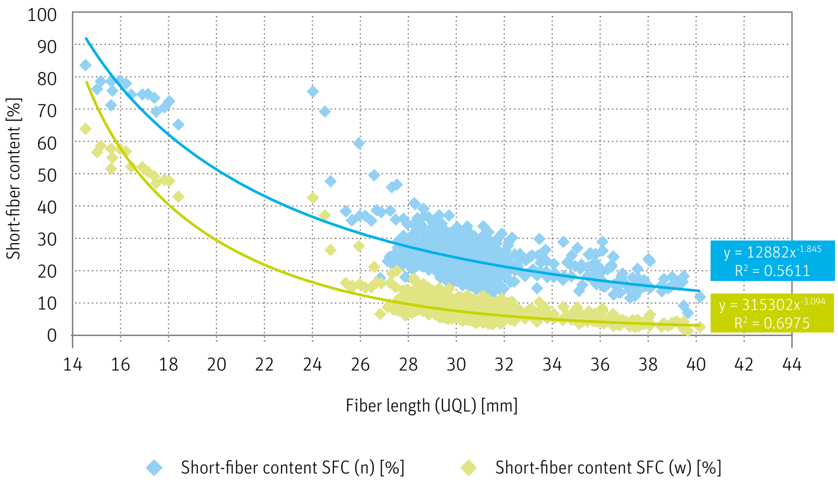


Fig. 2: Short-fiber content depending on the fiber length

Instrument: AFIS
Source: TIS Data 03/2020

3. Trial Setup

In order to be able to precisely determine the influence of the short-fiber content on the yarn quality and to eliminate variables that influence the raw material and therefore weaken the validity of the results, a West African cotton with a commercial staple of 1 7/32” was used and short fibers in different quantities precisely mixed in.

The increase in the short-fiber content came from the addition of noils. As Fig. 3 shows, the noil addition of 50% resulted in a raw material short-fiber content of approximately 54%, for example.

The comparison was built up on three production lines. One line as classical process with two draw frame passages, one line as shortend process with one single draw frame passage and one line as a direct process thanks to a module attached to the card, see Fig. 4 on the next page. With all three processes three different yarns were spun (Ne 30, Ne 20 and Ne 12) with different proportions of short fibers (from 100% virgin cotton to 100% noil). The short fibers were always blended in the blowroom.

Short-Fiber Content

Blend of virgin cotton and comber noil

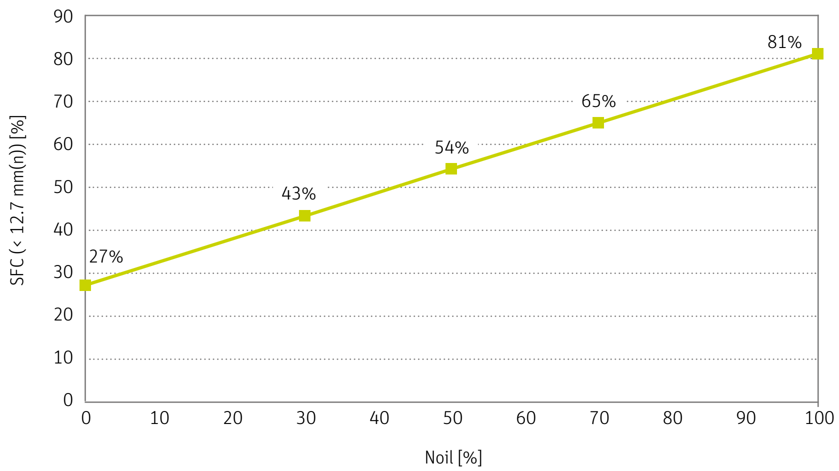


Fig. 3: Development of short-fiber content with varying amounts of noil

Instrument: AFIS
Source: TIS Data 03/2020

The following raw material blends were tested:

	Virgin Cotton (1 7/32”, 4.2 Mic)	**Noil (19/32”, 4.35 Mic)**	**Short-Fiber Content**
1	100%	0%	27%
2	70%	30%	43%
3	50%	50%	54%
4	30%	70%	65%
5	0%	100%	81%

In the trial, the optimal process sequence for the above-mentioned raw materials was examined. To do this, three different production lines were defined:

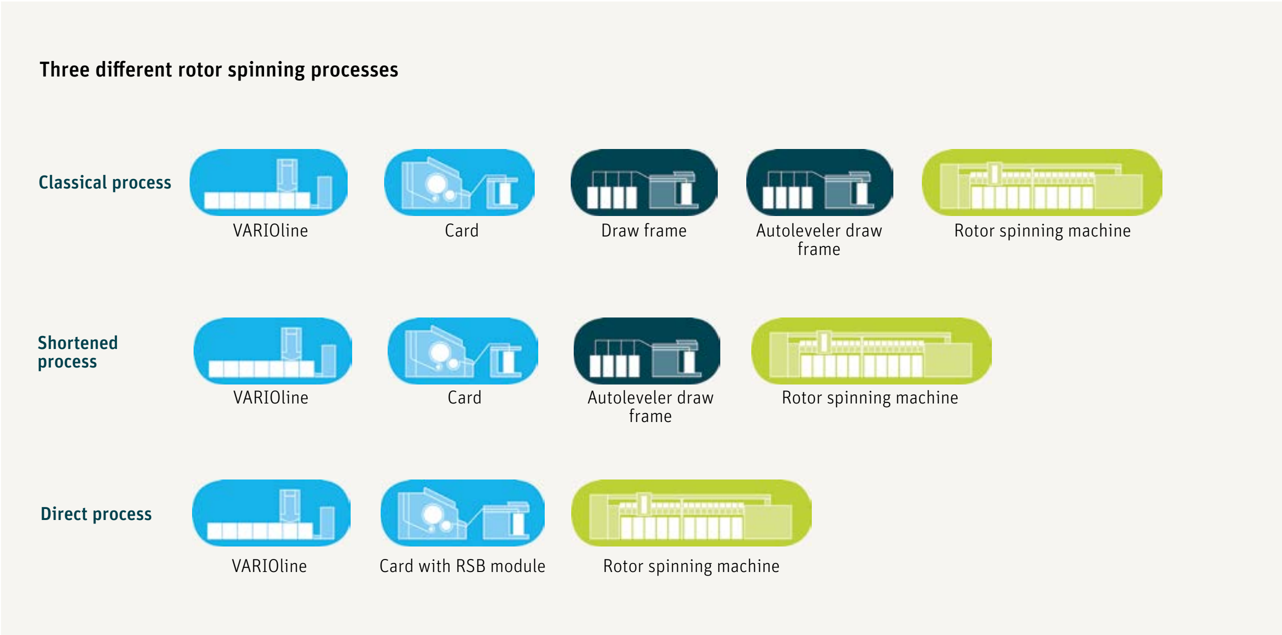


Fig. 4: Three processes were defined for the trial

All of the optimal settings in the spinning plan were identified and thus at the same time offer the basis for calculating the economical viability later.

Machine	Type	Infeed count [tex] / [Ne]	Doubl. [fold]	Draft [fold]	Delivery count [tex] / [Ne]	Twist [αm] / [T/m]	Delivery
Blowroom	A 11 – B 12 – B 36 – A 79						
Card	C 70		1	1	6 000 / 0.10 12 000 / 0.05		Virgin cotton 135 kg/h Noil blends 100 kg/h
Draw frame First passage	SB-D 15	6 000 / 0.11	5	5	6 000 / 0.10		Virgin cotton 750 m/min Noil blends 450 m /min
Draw frame Second passage	RSB-D 40	6 000 / 0.11	5	5	6 000 / 0.10		Virgin cotton 700 m/min Noil blends 400 m/min
Card with module	RSB module	12 000 / 0.05	1	2	6 000 / 0.10		
Rotor spinning machine	R 66	6 000 / 0.10	1	113	49.2 / 12	167 / 681	125 m/min 85 000 rpm
Rotor spinning machine	R 66	6 000 / 0.10	1	188	29.5 / 20	167 / 969	98 m/min 95 000 rpm
Rotor spinning machine	R 66	6 000 / 0.10	1	281	19.7 / 30	184 / 1 300	77 m/min 100 000 rpm

4. Optimal Process Sequence

4.1. Sliver Evenness and Adhesive Strength on the Intermediate Product

In recent years, it has been clearly proven that process shortening not only reduces the yarn conversion cost, but, depending on the end-spinning process and raw material, it can also significantly improve the quality. Prerequisites for this are drafting systems that include an efficient draft as well as a draft control in the shortened process. The higher the short-fiber content, the higher the risk of uncontrolled drafts. The effect can be seen clearly when the drafted fiber web which has not yet passed the web funnel is placed on a dark sheet.

With 100% virgin cotton, there is an even draft without drafting faults. Already with the addition of 50% noil, fiber package build-up can be seen. In extreme instances of 100% noil, it is clear that neither the classical process with two draw frame passages nor the shortened process with one draw frame passage can meet the yarn quality requirements, while the direct process using RSB module still achieves the requirements of evenness. This indicates that the optimal process sequence is dependent on the short-fiber content (see Fig. 5).

In the direct process with RSB module no drafting faults and fiber package build-up are seen in any of the raw material variants. The fiber web looked the same in all raw material categories, with no visible fiber package build-up. The higher the short-fiber content, the higher the risk of uncontrolled drafts. The use of an RSB drafting system module directly

Influence of number of draw frame passages on sliver with different short-fiber content

Classical process with two passages		Shortened process with one passage	Direct process with RSB module
First passage unregulated	**Second passage** regulated	**One passage** regulated	**Card with module** regulated
100% Virgin Cotton			
			In the direct process with RSB module the fiber web looked the same in all raw material categories, with no visible fiber package build-up. However, only one picture was taken.
50% / 50% Virgin and Noil Cotton			
			
100% Noil Cotton			
			In the direct process with RSB module the fiber web looked the same in all raw material categories, with no visible fiber package build-up. However, only one picture was taken.

Fig. 5: The ideal number of passages depends on the short-fiber content.

Source: TIS27312/Technology & Process Analytics after the card significantly reduces this risk. Furthermore, there is the advantage that when using the direct process and a high short-fiber content, the sliver adhesive strength is only slightly reduced, thus avoiding long-wave fluctuations in unevenness in the yarn.

The visual observations in Fig. 5 confirm the measurements on the sliver as can be seen in the following figures.

If the classical process is used, the evenness is reduced on the second passage above a short-fiber content of 50%. With 100% noil, due to the low sliver adhesion and the package warping, it was not possible to further process the slivers on the second draw frame passage.

From a noil addition of 30%, a significantly improved evenness on the sliver was achieved using the shortened process in comparison to the classical process (see Fig. 6).

In the direct process with RSB module, no significant trend could be seen here. In some cases, the evenness is reduced in the direct process comparison with the evenness after the autoleveler draw frame in the shortened process. However, this could not be seen later in the rotor yarn. The reason for this is that the sliver adhesive strength is another factor that positively influences the evenness of the rotor yarn.

Within the range of long-wave unevenness of 3 m, the classical and shortened process are both at the same level. The direct process with RSB module shows higher values (see Fig. 7), but this is hardly visible in the rotor yarn as will be shown later.

Sliver Unevenness over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio

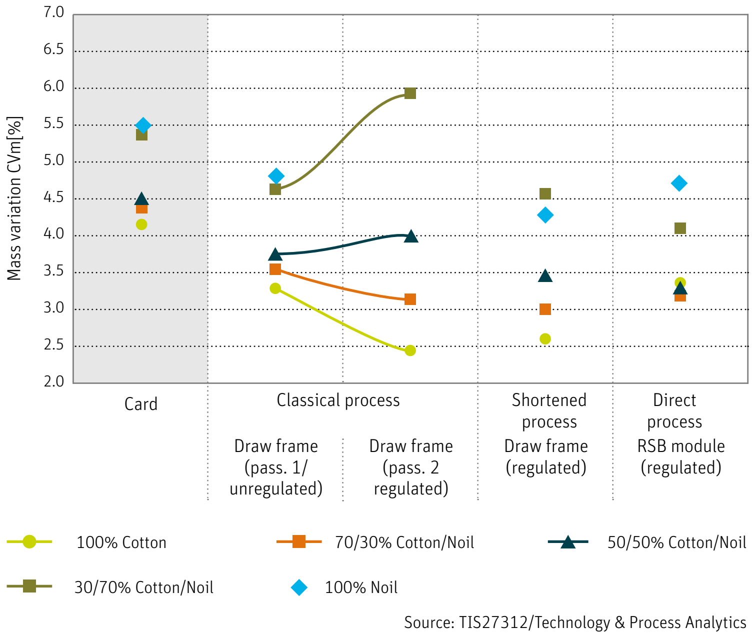


Fig. 6: At a short-fiber content of more than 50% the sliver unevenness is reduced with the classical process.

Long-wave Unevenness of the Sliver Over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio

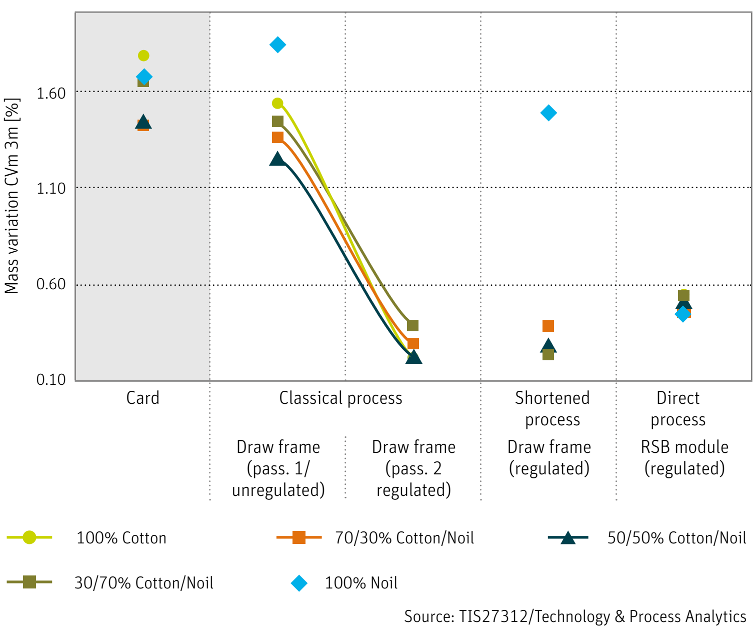


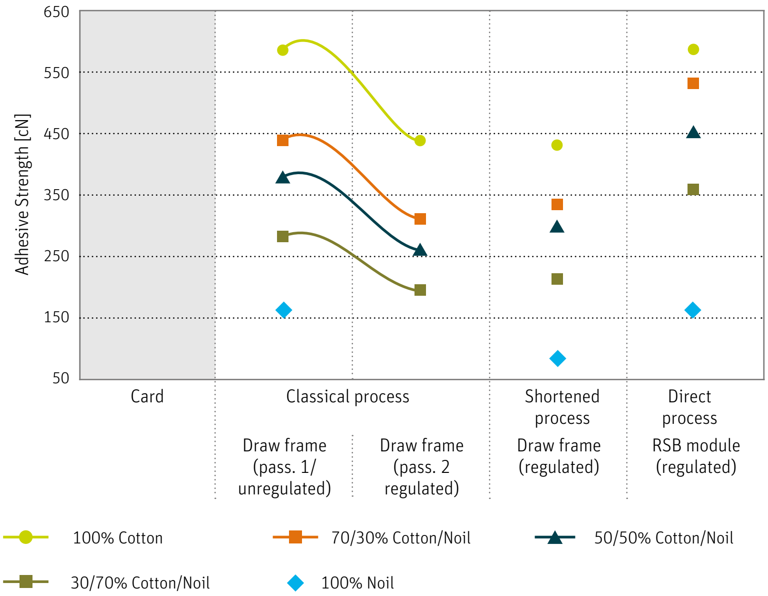
Fig. 7: The direct process shows an increase in sliver unevenness which is, however, not reflected in the yarn.

The adhesive strength of the slivers is significantly higher with the RSB module than in the other two process sequences (see Fig. 8). A higher adhesive strength in raw materials with higher short-fiber content will have a positive effect on the rotor spinning machine in the later spinning process.

Due to the higher degree of parallelization resulting from the higher draft and doubling of the slivers in classical and shortened processes, the adhesive strength is reduced, which can lead to drafting faults in the sliver.

If the adhesive strength of the slivers is too low, this can cause unregulated draft in the subsequent process steps, which negatively impacts the yarn evenness. This means that as the short-fiber content increases, the adhesive strength in the sliver becomes increasingly important. Alongside good sliver evenness, adequate adhesive strength of the sliver is required to ensure evenness in the rotor yarn.

Adhesive Strength (Rothschild) of the Sliver over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 8: The adhesive strength in the direct process with RSB module is significantly higher than in the other two processes.

4.2. Evenness of the Rotor Yarn

The classical process shows slight advantages for 100% virgin cotton raw material from CVm 0.2 to 0.3% when compared to the shortened process. From an addition of 50% noil and thus a short-fiber content of 55%, the evenness worsens. With 100% noil, due to the low or lost sliver adhesion, it is already no longer possible to produce a draw frame sliver on the first passage.

The higher the short-fiber content, the more significant the advantage of using a shorter drafting process. With an addition over 30% noil, the direct process with RSB module starts to show advantages. The evenness here is already on the same level as with the classical process.

As the short-fiber content increases, the advantages of the direct process with lower draft emerge significantly. There is a considerably better degree of unevenness compared with the other two processes (see Fig. 9).

To be able to show the effects of an optimal and sufficient sliver adhesive strength, the unevenness of a longer piece of yarn or over a larger yarn length measuring range must be taken into account. Yarn length measuring ranges are usually from 1 to 10 meters. The effects of the sliver evenness combined with the relevant adhesive strength of the slivers can already be seen very clearly at a yarn length of 1 meter.

This again demonstrates that from an addition of 50% noil, a clear benefit is shown as the process sequence becomes shorter. This means the general statement that increased doubling – i.e. more draw frame passages – always leads to advantages in long-wave yarn unevenness, is not always accurate. The reason for this is that the optimal process sequence is also hugely dependent on the short-fiber content.

Therefore, to retain a good yarn count, the process sequence must be adapted to the raw material, meaning it must be shortened as the short-fiber content increases. This is especially evident in the processing of 100% noil. In this case, it is not possible to produce a draw frame sliver with two draw frame passages as the sliver adhesion is too low (see Fig. 10).

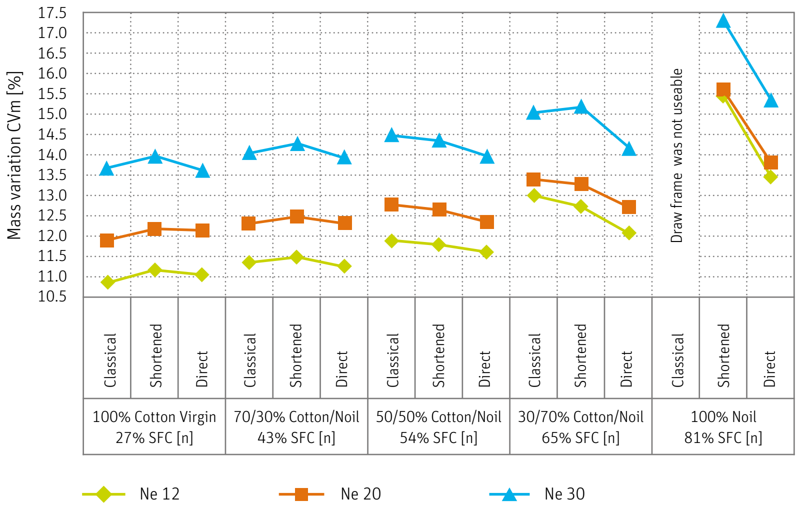
The higher the yarn cut length, at which the unevenness is determined, the smaller the differences between the individual processes. This means that as the short-fiber content increases, the optimal process sequence in the yarn length range of 0.02 to 3 meters is especially important. In single jersey knitted fabric, some irregularity may be seen in some unfortunate cases, for example a "cloudy" fabric appearance if a machine width from 1 to 100 cm or an average knitted fabric width of 30 cm is used.

4.3. Tenacity and Elongation of the Rotor Yarn

The yarn tenacity is greatly influenced by the short-fiber content. Therefore, the influences of the relevant process sequence on the yarn tenacity are secondary. The yarn tenacity decreases greatly as the short-fiber content increases (see Fig. 11).

The maximum noil addition or the short-fiber content and the resulting yarn quality reveal a lot about the possibilities of further yarn processing and the application range. For the weaving mill, an average tenacity of at least 12 cN/tex is required. Possible applications with an extremely high short-fiber content (according to the fiber count) of more than 65% are therefore very limited for the application range of the staple fiber yarns.

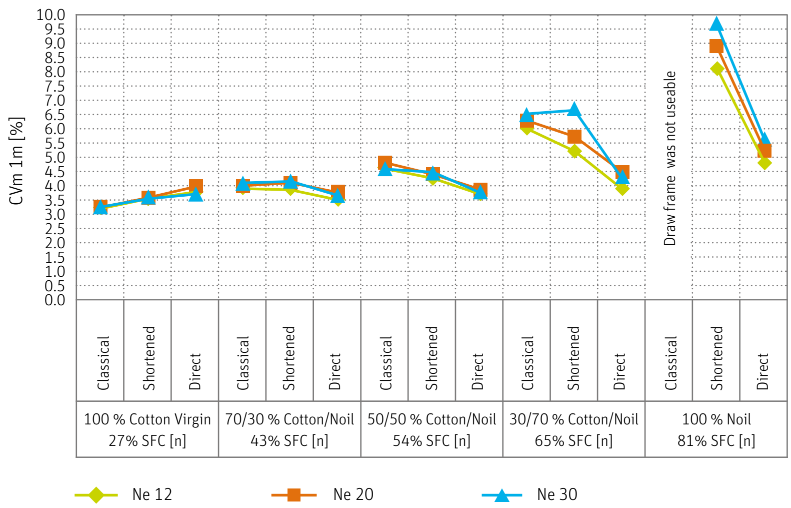
Rotor Yarn Unevenness over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 9: The direct process has a positive effect on yarn quality if the raw material has a high short-fiber content.

Long-wave Unevenness of the Rotor Yarn over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 10: The long-wave unevenness shows the same results as Fig. 9.

The average tenacity is certainly just one criterion for whether the yarn can be woven. Other key criteria include tenacity weak points and the number of weak points, the variation of the tenacity, the elongation values, etc. The consideration of the tenacity value should only indicate that the market content or the application range is reduced for extremely high short-fiber content due to the huge decrease in tenacity. This therefore results in the widest application range where raw materials with a high short-fiber content up to 65% are processed.

For yarn counts of Ne 12 to Ne 20, the elongation only differs slightly between the different processes and raw materials. The short-fiber content only begins to have a negative effect with finer yarns (see Fig. 12). This can be explained by the fact that the yarn elongation is primarily dependent on the following influencing parameters:

- Raw material type (cotton, man-made fiber, etc.)
- Yarn count (yarn bulk)
- Yarn structure (end-spinning process)
- Spinning tension (production amount, machine settings, technology components)
- Raw material composition (blend within the same raw material type)

Breaking Tenacity of the Rotor Yarn over Different Process Stages

100% Cotton, 1 7/32" with different noil ratio

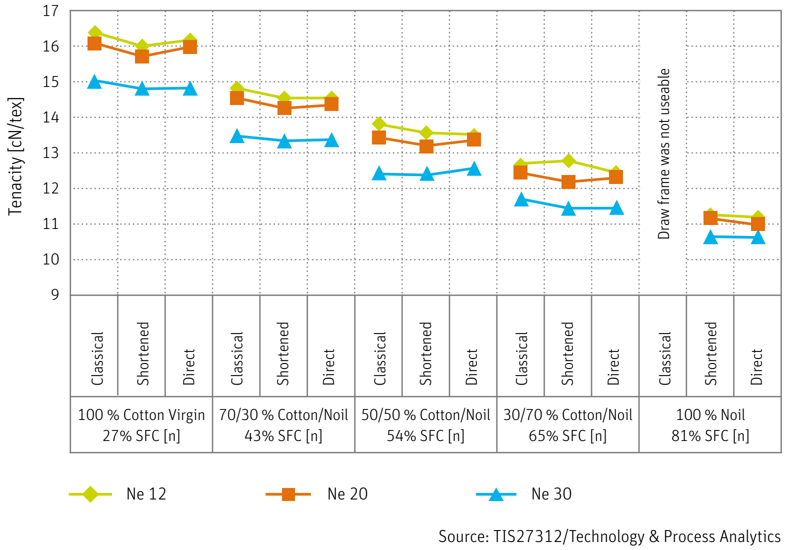


Fig. 11: The yarn tenacity decreases linearly and massively with increasing short-fiber content.

Breaking Elongation of the Rotor Yarn over Different Process Stages

100% Cotton, 1 7/32" with different noil ratio

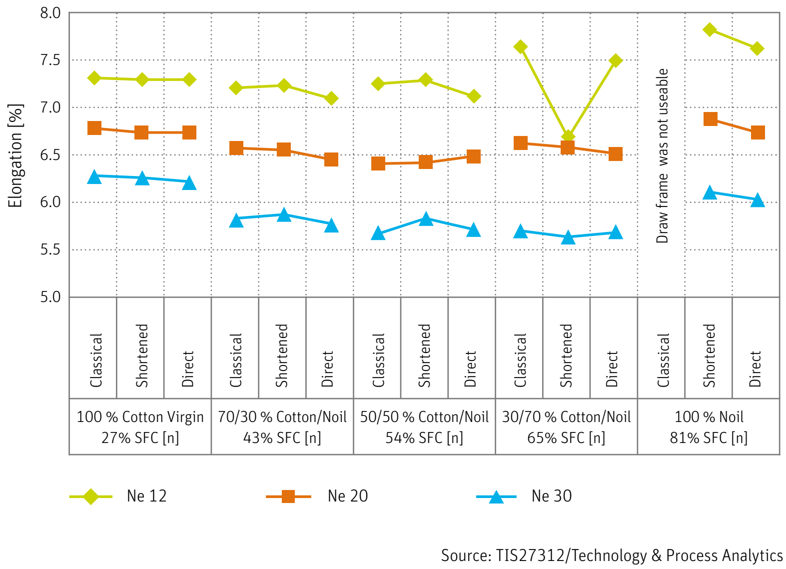


Fig. 12: Only with finer yarns the short-fiber content has a negative effect on elongation.

4.4. Hairiness and Abrasion of the Rotor Yarn

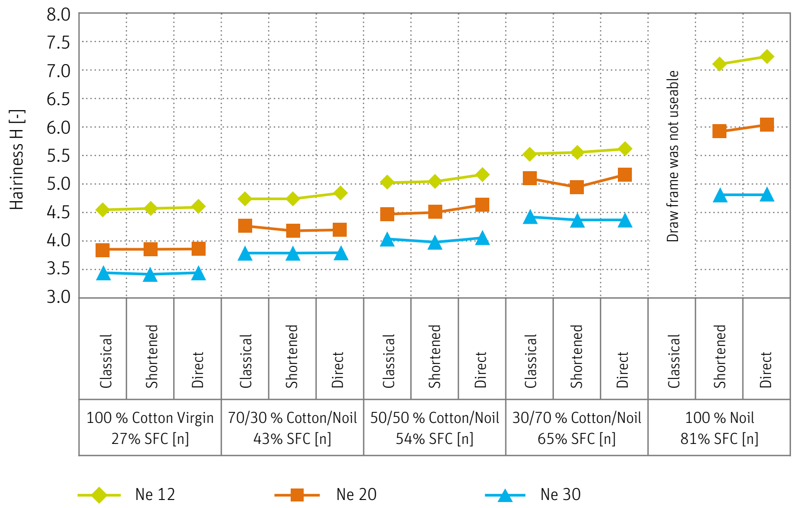
The process sequence only marginally influences the yarn hairiness if the same end-spinning system is used, i.e. the yarn has the same structure. In addition to the yarn count, hairiness is primarily determined by the short-fiber content. The higher the short-fiber content, the greater the hairiness.

Especially in rotor spinning, hairiness can certainly be influenced by the choice of nozzle – to a certain extent. However, this has an adverse effect on yarn tenacity and is not relevant in the context of this study.

The hairiness is in turn directly related to yarn abrasion, which is an important criterion for further processing – this is due to fiber fly or fiber build-up during knitting or weaving. The higher the short-fiber content, the greater the hairiness and therefore also the abrasion. Fiber fly in the knitted fabric or woven material can lead to complaints and second-quality products if the machines are not cleaned sufficiently (see Fig. 13 and 14).

Rotor Yarn Hairiness (Uster) over Different Process Stages

100% Cotton, 1 7/32" with different noil ratio

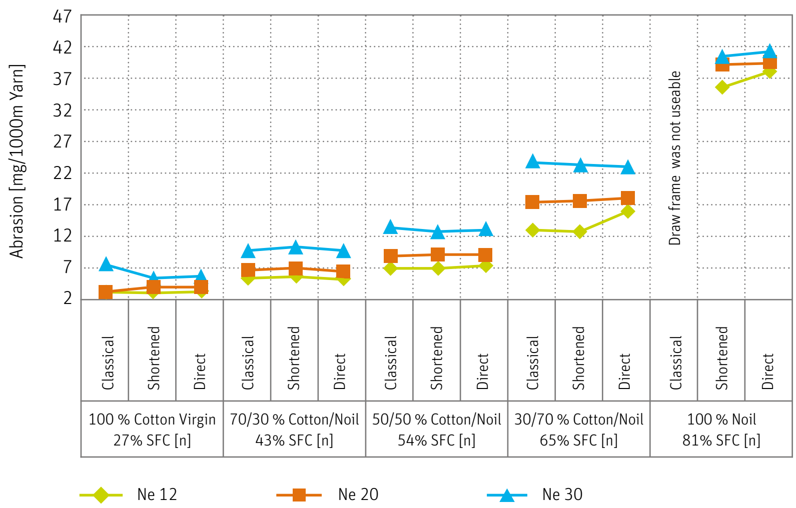


Source: TIS27312/Technology & Process Analytics

Fig. 13: Hairiness is mainly influenced by the short-fiber content and less by the process sequence.

Rotor Yarn Abrasion (Staff test) over Different Process Stages

100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 14: The higher the proportion of short fibers, the higher the hairiness and thus also the abrasion.

4.5. Running Behavior of the Rotor Spinning Machine

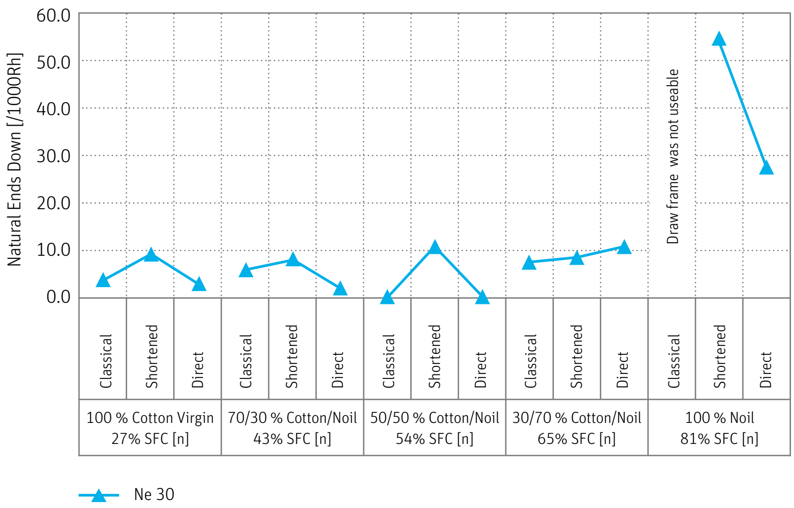
The rotor speed and yarn twist were adapted to the raw material with 100% noil in order to achieve comparable conditions and the best-possible spinning conditions.

Already from a short-fiber content of approximately 65%, a slight increase in ends down can be observed. With only 50 ends down and approximately 50 further quality cuts per 1 000 rotor hours and a yarn count of Ne 30, it can be said that the rotor spinning machine has an excellent running behavior.

Even with a short-fiber content of 80%, which corresponds to 100% noil content, the natural ends down and cleaning cuts would be in an excellent range with a total of 130 per 1 000 rotor hours – provided the direct process is used.

The advantage of the direct process compared to the classical process with 280 interruptions per 1 000 rotor hours is clearly visible (see Fig. 15).

Running Performance of the Rotor Spinning Machine over Different Process Stages
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 15: The direct process is in line with the other processes in terms of natural ends down. With a very high short-fiber content the direct process has great advantages.

5. Advantages of the RSB Module with two Draft Zones

The direct process with a draw frame module indicates clear advantages in terms of quality and also the quality cuts on the rotor spinning machine as the short-fiber content increases. However, the question of how the drafting system must be designed on the card for the direct process is also important. There are different solutions on the market which use either one or two draft zones on the drafting unit.

In order to determine which drafting system design is advantageous, the Rieter RSB module 50 was used on the card (see Fig. 16). To investigate the technological properties, this module with two draft zones (break draft and main draft) was compared to another version of the module which simulated only one draft zone (main draft). In order to ensure exact leveling in the case of one draft zone, the leveling action point was adapted to the new conditions. The test was carried out on three different raw material variants with different short-fiber contents.

Autoleveler Draw Frame Module Rieter RSB-Module 50 with Two Draft Zones

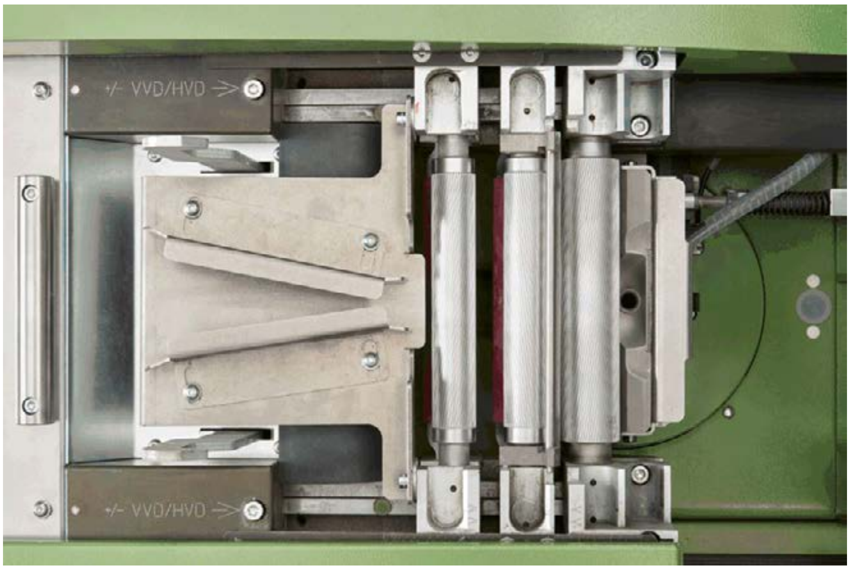
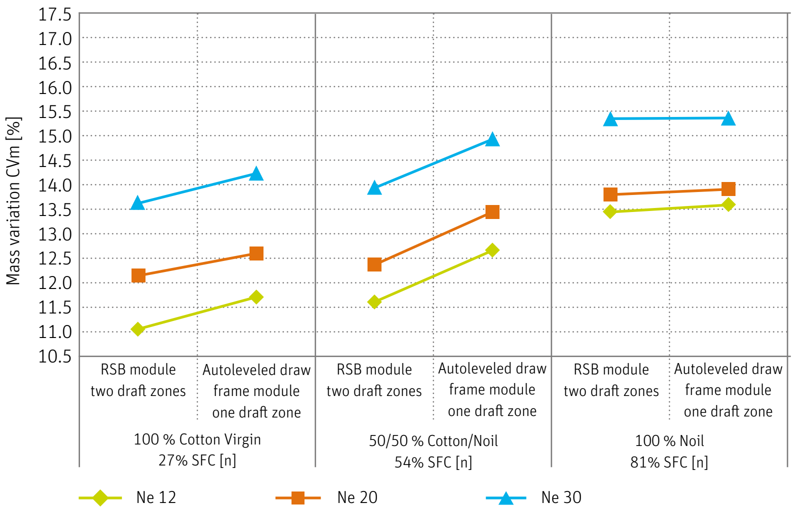


Fig. 16: The design of the drafting system in the direct process plays an important role.

With a short-fiber content of 54%, improved evenness can be seen for the drafting system with two draft zones in the RSB module. Only with a short-fiber content of 81%, which is rather rare in applications on the market, the values of one and two draft zones are the same. However, with such a high short-fiber content in the longer sliver cut lengths, two draft zones are slightly more favorable (see Fig. 17 and 18).

Criteria such as neps, tenacity, elongation, hairiness and wear are not influenced by the number of draft zones. As with the evaluation of the process sequence, these criteria only depend on the short-fiber content or the raw material and yarn count.

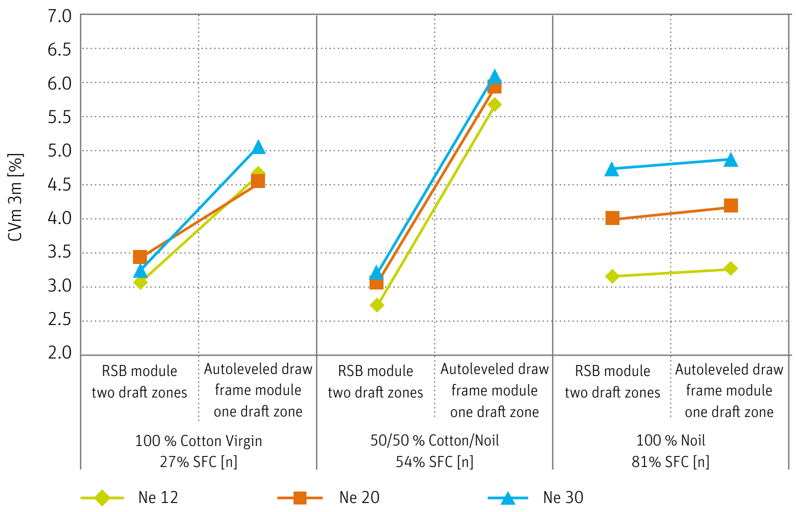
Rotor Yarn Unevenness over Draft Zones
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 17: The evenness of the rotor yarn is significantly better with two draft zones.

Long-wave Unevenness of the Rotor Yarn over Draft Zones
100% Cotton, 1 7/32" with different noil ratio



Source: TIS27312/Technology & Process Analytics

Fig. 18: Also with a longer piece of yarn, two draft zones are an advantage.

6. Effects on the End Product

The technical values of the yarn often leave open the question of the extent to which the changes are reflected in the end product. To answer this question, the yarns from the various rotor process systems were used to produce single jersey knitted fabric in raw white. The differences are very clearly visible and would become even more clear depending on the dye or color.

The best evenness was achieved using the classical process with virgin cotton. With a noil addition of 30% (short-fiber content of 45%), there are hardly any visual differences between the individual processes.

A clear difference in favor of the direct process can be seen with a noil addition of 70% or a short-fiber content of 65%. The difference in favor of the direct process is even clearer with 100% noil (short fiber content 80%). In this respect, it can be said that the technical differences are clearly visible on the yarn in the knitted fabric. Comparing the direct process with one or two draft zones, the one with two draft zones produces the fabric with a better evenness.

100% Virgin Cotton, Ne 30, Single Jersey

Classical process | Shortened process | Direct process – two draft zones

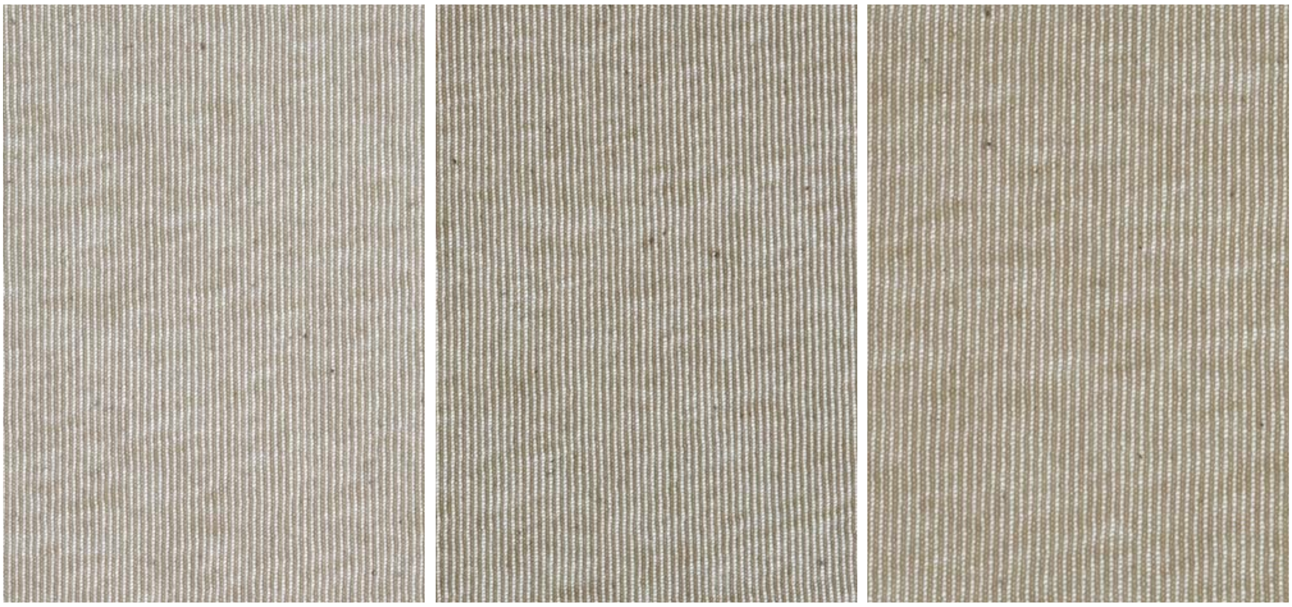


Fig. 19: With 100% cotton, the best evenness was achieved using the classical process. Source: TIS27312/Technology & Process Analytics

70% Virgin Cotton / 30% Noil, Ne 30, Single Jersey

Classical process | Shortened process | Direct process – two draft zones

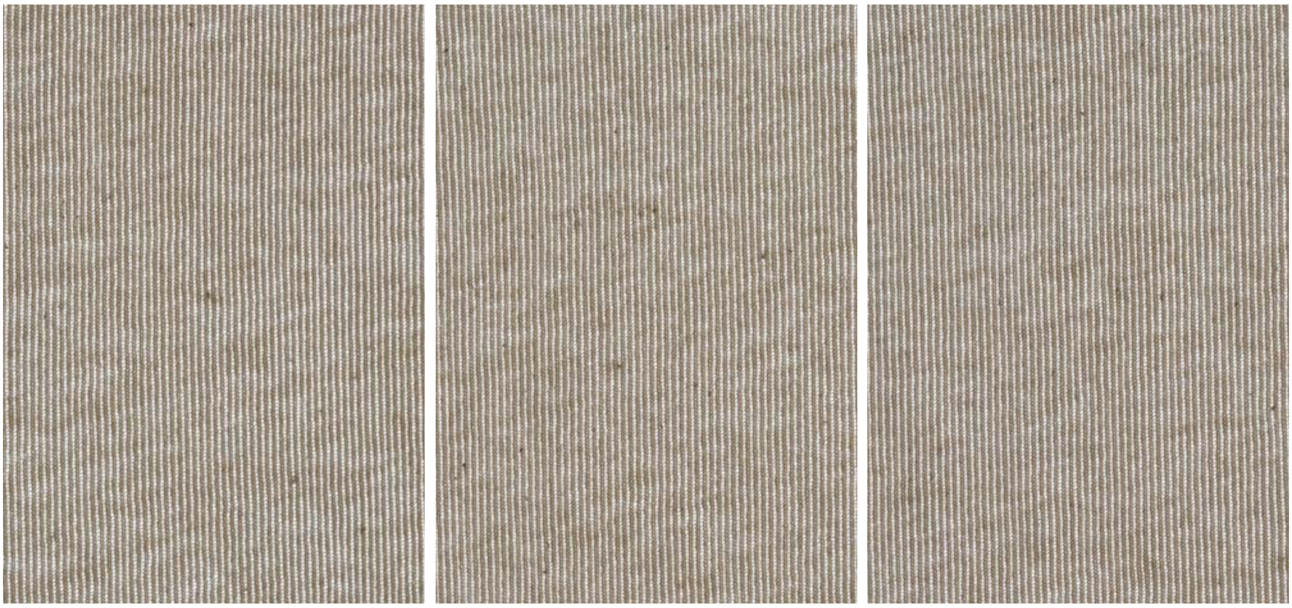


Fig. 20: With 70% cotton and 30% noil, there are hardly any visual differences between the processes. Source: TIS27312/Technology & Process Analytics

30% Virgin Cotton / 70% Noil, Ne 30, Single Jersey

Classical process | Shortened process | Direct process – two draft zones

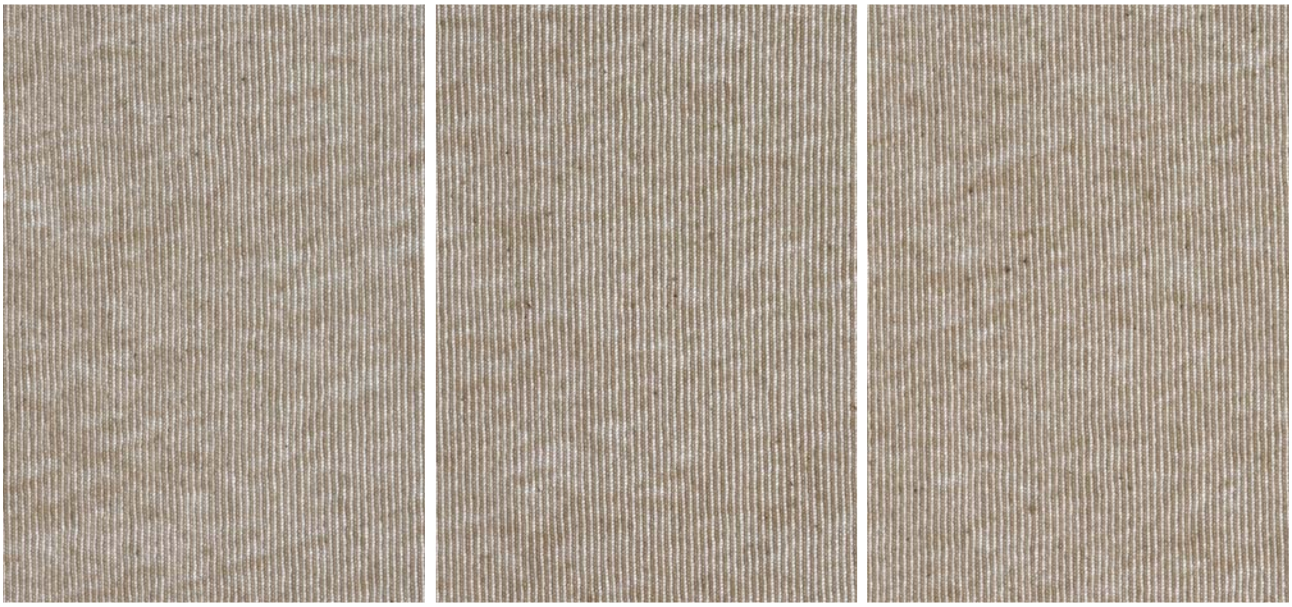


Fig. 21: With 30% cotton and 70% noil, a clear difference in favor of the direct process can be seen. Source: TIS27312/Technology & Process Analytics

100% Noil, Ne 30, Single Jersey

Shortened process | Direct process – two draft zones | Direct process – one draft zone

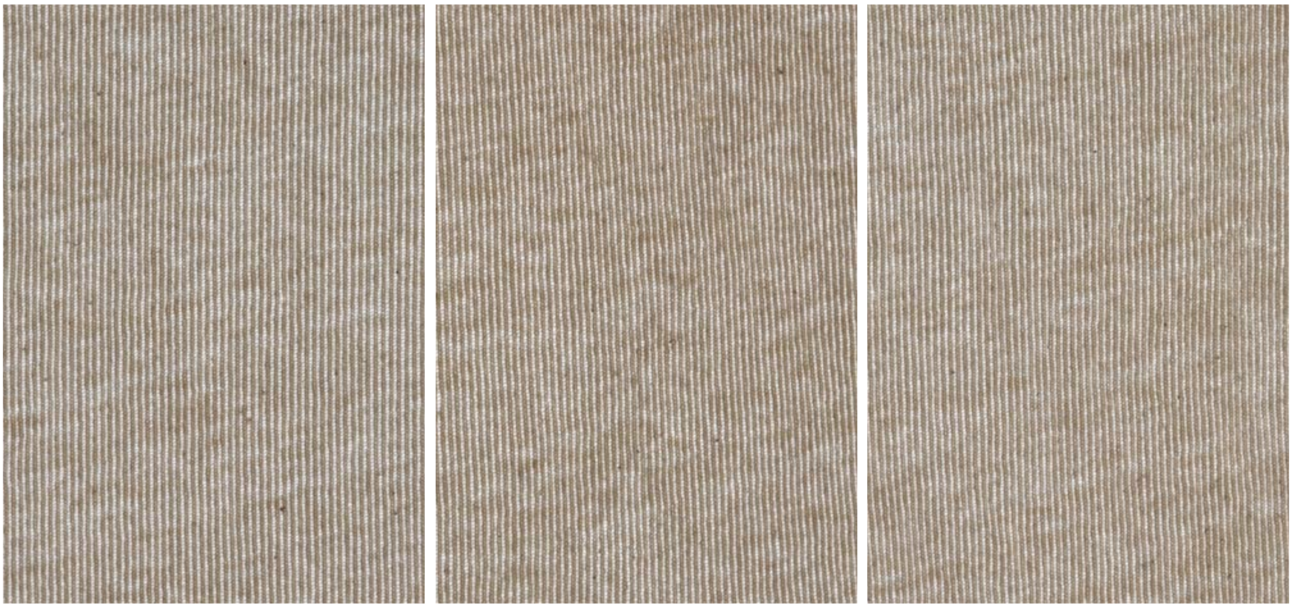


Fig. 22: With 100% noil, the difference in favor of the direct process is even clearer. Source: TIS27312/Technology & Process Analytics

50% Virgin Cotton / 50% Noil, Ne 30, Single Jersey

Direct process – two draft zones | Direct process – one draft zone

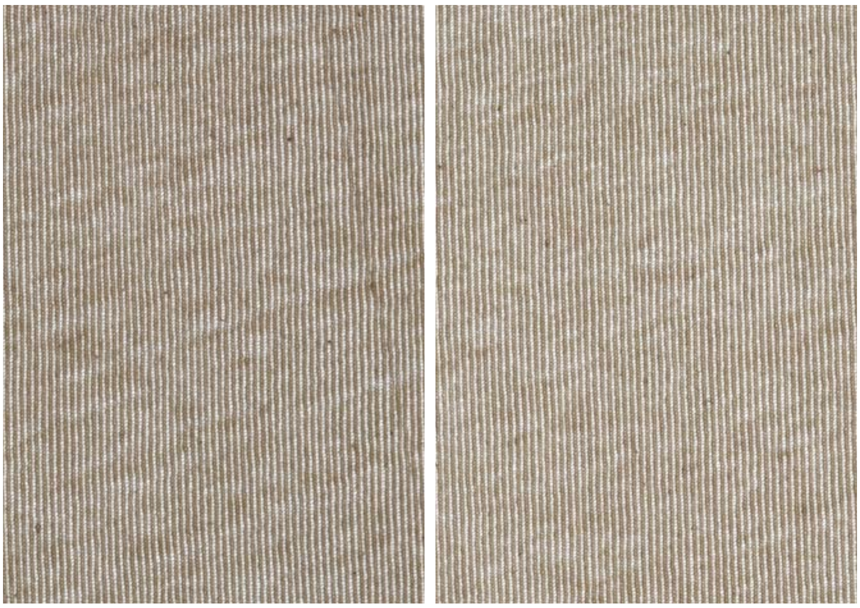


Fig. 23: Comparing the direct process with one or two draft zones,
the one with two draft zones produces the fabric with a better evenness.

Source: TIS27312
Technology & Process Analytics

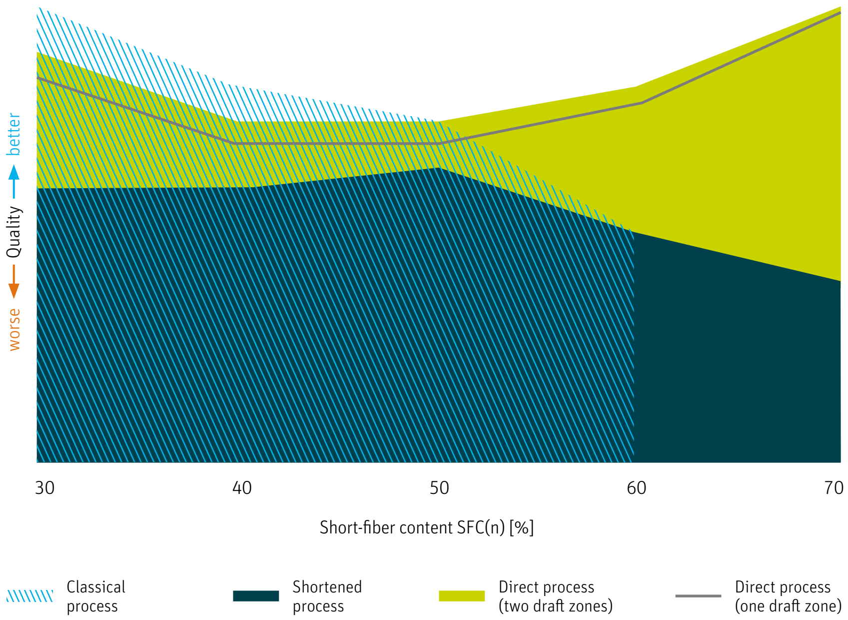
7. Process Recommendation

When all yarn parameters are evaluated, along with their effects that are reflected in the knitted fabric, the following process recommendation can be made for the rotor spinning system depending on the short-fiber content when using cotton:

- With a short-fiber content up to a maximum of 50%, the classical process with two draw frame passages is advantageous, especially in terms of unevenness.
- Above a short-fiber content of 50%, the direct process with RSB module shows strengths and performs better than the classical process.
- The direct process can be used from a short-fiber content of 40%.
- Above a short-fiber content of 65%, the direct process must be used due to the required sliver adhesive strength.
- In the case of the direct process, two draft zones are recommended (see Fig. 24).

Process Recommendations for Rotor Spinning System

100% Cotton, 1 7/32" with different noil ratio, rotor yarn



Source: TIS27312/Technology & Process Analytics

Fig. 24: Above a short-fiber content of 65%, the direct process must be used due to the required sliver adhesive strength.

8. Economic Viability

There are generally low margins on rotor yarns and any improvement in conversion costs or technology helps spinners to secure profitability. To evaluate the economic viability, an example of a classical process is compared with a direct process for 100% virgin cotton for a Ne 20, see Fig. 25.

This example – taking Turkey as a basis for the calculations – shows that the savings in conversion costs of about 211 000 USD (mainly the labor cost) with the direct process (integration of an auto leveling draw frame on the card) are already a great advantage in this very competitive market.

Additionally, profitability can be improved by reducing raw material cost. Instead of using 100% virgin cotton, noil can be added. By doing this, yarn properties are dropping. However, if the requirements for downstream processes are still met, there is tremendous cost saving potential in the raw material cost reduction. For the above described example, raw material savings of several million USD per year are possible.

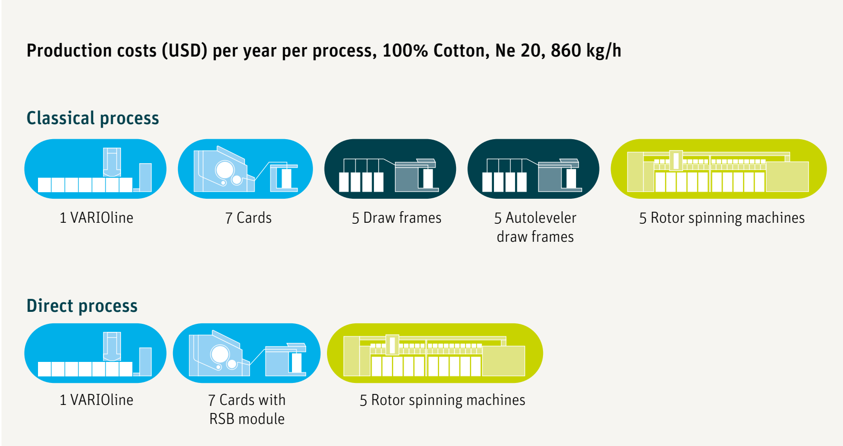


Fig. 25: With the direct process significant cost savings are possible.

Cost savings with the direct process compared to the classical process (calculation basis Turkey)

Cost of waste	-4%
Labor cost	-25%
Energy cost	-2%
Cost of auxiliary material	-3%
Capital cost	-7%
Total	**211 000 USD cost savings per year**

Cost savings in raw material by adding short fibers to virgin cotton

	Price (USD/kg)	**100% Virgin cotton**	**Virgin cotton/ noil blend**
Virgin Cotton	1.78	100%	50%
Noil	1.10	0%	50%
Total costs (USD/kg)		1.78	1.44
Costs (Mio. USD/year) per process line (860 kg/h)		**13.0**	**10.5**
Cost savings (Mio. USD/year) per process line (860 kg/h)			**2.5**

9. Summary

The optimal process within the end-spinning system greatly depends on the raw material. For example, the decisive criterion for processing cotton is the short-fiber content.

Shortening a process can bring huge advantages in terms of quality. However, it is important that the machine design of the module on the card also brings the relevant advantages.

Findings for Rotor Spinning

- For a high short-fiber content, the direct process is far more advantageous than the classical process with two draw frame passages in terms of yarn unevenness, thin/thick places and count retention.
- For a short-fiber content up to a maximum of 50%, the classical process is advantageous, especially in terms of unevenness.
- Above a short-fiber content of 50%, the direct process shows strengths and performs better than the classical process.
- Above a short-fiber content of 65%, the direct process must be used due to the required sliver adhesive strength.
- For a short-fiber content of 80%, the quality interruptions on the rotor spinning machine during the direct process are approximately 50% lower compared to the classical process.
- The direct process has no negative influence on the elongation, tenacity and neps.

Findings for the Specification of the Direct Process with RSB Module

- When using the direct process, a drafting system with two draft zones on the RSB module of the card is favorable in terms of improved evenness for a short-fiber content of up to 80%.

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