Innovations in spun yarn technologies—Present and future

W Oxenham
College of Textiles, North Carolina State University, Raleigh, NC 27695-8301, USA

Globalization has profound effects on the textile industry, including yarn production. These effects are not only evident in shifts in the geographical bases of production but also in the ‘drivers’ for manufacturing. This means that yarn producers are expected not only to produce higher quality yarns on much shorter lead times, but must also be competitive on prices in order to survive. A modern yarn producer must therefore be technologically aware, efficient, flexible, and cost conscious. The majority of recent developments in yarn production have been refinements of existing techniques plus improvements in process and product quality. While there are potentially many techniques that could be used to produce yarns, many have met with limited commercial success. Automation is an obvious way to reduce labor costs and improve quality; however, this often carries the penalty of reduced flexibility. Competing on pricing is a prerequisite to survival and the major component of yarn price in a modern spinning mill is the cost of the fiber. Thus, any saving made in raw material directly impacts possible profits. This paper reports the above aspects and their possible interactions.

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1 Background and Spinning Demographics

During the 60s and 70s there was a tremendous amount of research on ‘new spinning technologies’. This resulted in a few successful, commercially adopted systems and many more failures. Since that time, there has been a dramatic reduction in research activity in this area but there have been continued refinements in existing technologies. Throughout this time the developments in spinning machinery have been less prolific and this is no doubt associated with the changing markets for machinery. Additionally, there is a much lower market share occupied by long staple spinning and thus machine makers have focused on the dominant (representing over 90% of installed spindles) short staple spinning machines. An additional consideration with respect to the developments in spinning equipment is the fact that while the production of cotton has increased and the production (and consumption) of wool has remained fairly constant (Fig. 1), the natural fibers share of the fiber market has continued to diminish (Fig. 2). A further factor for the reduced research and development in staple spinning technology is that there has been a downturn in sales of spinning machines (about a 30% reduction between 2002 and 2003) which obviously impacts possible research budgets.

It is also interesting to note that there has been a significant shift in the manufacturing base which is primarily associated with manufacturing costs, as is evident from Fig. 3 (ref. 3). Thus, while it is clear from Table I (ref. 4) that there have been shipments to Europe, North America and Asia, these have essentially been to three counties, namely Turkey, Mexico and China. It is, however, claimed that even in these countries of recent growth, there appears to be slowing down in investment.

2 Possible Spinning Technologies

There have been many potential innovations in spinning which have met with limited success for
various reasons but, in general, the primary limitation has been associated with an inability to match the quality of yarns and ultimate fabrics produced by ring spinning. Figure 4 illustrates the various spinning systems available and their potential processing speeds; the shading represents their present and potential acceptance as a commercial technique. Solid shading is used for those systems which have met with significant success, horizontal shading for those systems with small niche areas but no likely major acceptance, and the remainder is for systems which have found some usage or may have potential. Within each technique, there may be variants and specific components which differentiate the various machinery makers and may make a technology more applicable to a certain fiber type.

3 Spinning Technologies of Limited Success
Briefly, this group of possible spinning technologies includes:

3.1 Wrap (Hollow Spindle) Spinning
While this system was capable of producing 'high-quality' yarns at relatively high speeds, it was not widely accepted for 'normal' yarn processing. Yarns strength and uniformity were as good, if not better, as conventional yarns and the fabric abrasion and pilling were superior.5 Problematic was the presence of wrapping filament which could impact handle (in particular stiffness) and potentially limit the wider acceptance of this type of yarn. It has found use in some coarse yarn applications (such as upholstery yarns), fancy yarn production and technical yarns. All of these are, however, best considered as small markets which are susceptible to variable demand induced by fashion changes.

3.2 Twistless Spinning
While this system was heavily studied for use on cellulosic fibers, the promise of softer fabrics with good abrasion and pilling properties was never
commercially realized. The major problem was finding temporary adhesive which could easily be applied and removed, produced acceptable bonding, and was inexpensive. The use of soluble binders in wrap spinning offered an alternative route to twistless fabrics. However, while experimental trials showed that fabric aesthetics were outstanding and performance attributes were reasonable, the high cost of soluble binders precluded wide acceptance of this technique.

3.3 Felted Yarns
The technology of continuous yarn felting arose out of a need to find an alternative to the batch process of felting skeins (or hanks) of carpet yarns, which was being adopted as an approach for improving the appearance retention of certain carpet styles. Several techniques were available and it became apparent that the continuous felting process could in fact be a 'spinning system' when fed with suitable slubbings (ropings), rovings or slivers. While potential uses were explored for these novel yarns, it was clear that their market was primarily for carpets and then only for specific styles, which unfortunately were subject to fashion cycles. More recently, the introduction of the Fehrer Yarn Puncher offered an alternative approach to consolidate yarns, which is purely mechanical and thus can be applied to fibers other than wool.

3.4 Self Twist Spinning
Self-twist spinning was developed for the processing of wool fibers for knitting (ST) and weaving (STT) yarns. While it met with some initial success, particularly in processing polyester wool blends, and research was carried out into the possibilities of this system for short staple fibers, the main commercial usage was for high bulk acrylic knitting yarns. The problems with the system were primarily associated with unwanted patterning produced by the cyclic change in the twist. There has been a re-emergence in interest in this system with the recent introduction of the Macart Spinning System S300 which essentially is a modified Repco system but processes sliver through to fully relaxed yarn in one integrated machine. There has also been interest in the use of alternative twisting units with particular attention given to air twisters since it may be possible to randomize twist and twisting cycles and thus enable more acceptable fabrics to be produced.

4 Ring Spinning and its Variants
There is absolutely no doubt that ring spinning is the most successful spinning system for all types of staple fiber and there are presently in excess of 170 million spindles installed, with about 10% of these for long staple fibers. While the yarns and subsequent fabrics produced by this system may not excel in all respect (for example it is possible to produce stronger or more uniform yarns), they represent an ideal blend of attributes which make them outstanding for many apparel and technical applications. The major drawbacks of the system are:

- Low production speeds,
- Limited package size,
- Need to utilize rovings, and
- Yarn hairiness, necessitating additional twisting (folding).

The technology behind ring spinning has remained largely unchanged for many years but there have obviously been significant refinements, taking a system that was considered to be old and ready for replacement in the 60s, through to a 'high tech' machine which occupies a dominant position in the industry, that no one can foresee being usurped. These changes consisted of several improvements, which on their own offered only slight advantages. Fortunately, these developments combined synergistically and thus,

- the introduction of longer frames reduced the relative costs of automatic doffing,
- the combination of spinning frame and winding (link winders) further enhanced the adoption of automation,
- the introduction of automatic doffing meant that doffing time was reduced and thus package and ring size was less critical,
- the introduction of splicing on the winder meant that yarn joins became less obtrusive – again offering the potential of smaller package,
- smaller rings meant that for a limiting traveler velocity (40m/s) higher rotational speeds (and hence twisting rates) could be achieved, and
- in-line setting of twist and automatic transport of packages to twisting frame significantly reduce labor and could improve the economics of the total system.

These combinations meant that the potential maximum speed of ring spinning could be significantly raised.
In addition to the above improvements, there have been several other proposed developments which have met with mixed success. Specific examples of these proposals are described below.

4.1 Drafting Systems
While double apron drafting dominates, it has been demonstrated that the system can be tweaked to enable higher drafts and the recent exhibitions have featured short staple machines operating at potential drafts of 70-100. High drafts have been shown to be possible for long staple processing using multizone drafting systems, and while these developments primarily focused on unconventional systems, it seems reasonable to assume that they could be adapted to ring spinning. The use of high drafts had significant impact on the economics of the total system and the current debate is whether to feed lightweight slivers (like Suessen RingCan) or heavy weight roving (being promoted by Zinser).

4.2 Individual Spindle Drives
Several manufacturers demonstrated this possibility in the 80s and more recently a system has been exhibited by Howa (DDS system). While the concept offered advantage with respect to lower energy requirements, less noise and better control of speed, it suffered the major disadvantage of higher initial costs and bigger spindle gauge.

4.3 Ring Design
Several approaches for reducing the limitation imposed by traditional rings and travelers have been proposed and these include:
- Orbit rings—A development from Rieter that was aimed at increasing the dissipation of heat from the traveler.
- Ceramic rings (Ceratwine system)—The combination of a ceramic ring and ceramic-coated traveler offers the promise of significantly better wear resistance, which translates into long traveler life. Additional claimed benefits are more consistent yarn quality and shorter break in time.
- Rotating rings—This idea was tried by several ring frame manufacturers in the 70s and recently exhibited again by Howa. Other ventures into this area included systems, such as Cerifil, magnetic spinning system, and super traveler spinning system. The 'magnetic spinning system' utilizes a magnetically supported ring to replace the conventional ring and traveler. The ring thus guides the yarn onto the package and creates drag to provide winding tension. The super traveler system replaces the traveler with an annular guide, which slides in a track around the package. Visually, the system resembles traditional cap spinning or the more recent Cerifil. The problem with these types of devices is that while they appear to operate at lower spinning tensions, and thus potentially offer lower end breakage rates, they suffer a major drawback. This is that they usually create very short duration (high frequency) and high magnitude tension peaks, because of the inertia of the twisting element (which is significantly higher than a traveler).

4.4 Spindle ID
The tracking of spindles from the ring frame has great potential for process quality control and systems are available from several manufacturers. This enables the identification of those spindles on the ring frame that are responsible for producing defective yarns (as assessed on the winding frame). It is believed that the use of this type of system will result in improvements not only in yarn quality but also in efficiency by more readily indicating faulty positions on the spinning frame.

4.5 Longer Machines
Improvements in the drives used on spinning frames have enabled the number of spindles per machine to be further increased up to 1488 (Zinser). This has a positive impact on the cost per spindle. Additionally, as indicated above, the longer machines favor the use of automation, particularly link-winding.

4.6 Compact Spinning
Systems, that use additional drafting components and pneumatics to create yarns that are less hairy and stronger, are available from several machinery makers (Fig. 5). The many claims made for these systems are usually mutually exclusive (i.e. you can either have a stronger yarn or spin at higher production speeds with lower twist), and there is a significant increase in the cost of these machines and the yarn thereby produced when compared to traditional spinning frames. Much of the advantages made for the system center around the lower hairiness of compact yarns, which are claimed to improve subsequent processing costs. While the initial development was centered on cotton processing and the long staple systems were
simply adaptations, there are several newer systems which are specifically designed for worsted processing. These include units from Gaudino, Zinser and Cognetex (Fig.6). While it could be argued that this added competition may result in reduced machinery costs and potentially benefit spinners, this is unlikely since with the present downturn in spinning machinery sales, the development costs must be amortized over fewer machines. The entry of these newer players into the compact spinning arena is intriguing since it is assumed that a market has been identified, despite the difficulties encountered by other machinery makers. While the system is being promoted because of its lower hairiness and improved physical characteristics, this comes at the penalty of increased initial investment (up to 100% over the cost of a traditional machine), and increased maintenance which ultimately result in higher yarn prices (typically +20%) (ref. 18). It is intriguing that the recent developments are aimed at narrowing the width of the drafted strand so that a more compact (less hairy) structure is created. This was of course available many years ago when Ambler Superdraft spinning was (unsuccessfully?) introduced. This system utilized a modified drafting system incorporating a flume which condensed the fibers entering the front roller of the drafting zone and the net effect was very similar to the current claims for compact spinning. 19

4.7 Sirospun and Variants

Sirospun was an earlier attempt for creating a weavable worsted yarn directly from the spinning machine. The system is a double roving spinning system with a specific, optimum, separation of the roving so that the twist travels up the individual drafted strands and some of this twist is ‘locked’ into the structure when the strands converge (Fig. 7). This yields a yarn with lower hairiness and has been utilized commercially since 1980s, and despite drawbacks (such as twist liveliness, higher two-fold knots and knot slippage) it is claimed to have been well adopted in China. 20

A recent ‘development’ in this technology is the recently introduced EliTwist (Fig. 8) which essentially combines the technologies of double
roving spinning with compact spinning. The claims made for the system are that it affords significant advantages in yarn properties when compared to sirospun and conventional two-fold yarns.\textsuperscript{21}

4.8 Solospun

It is interesting to note that while most machinery makers are promoting the concept of reducing the width of the fiber strand emerging from the drafting system in order to produce more compact and less hairy yarn, solospun adopts exactly the opposite philosophy. By taking the sirospun yarn formation process to extremes, the issuing drafted strand is divided into many discrete strands, into which twist can run by an additional clip-on separator roll (Fig. 9). This is claimed to yield yarns with higher tenacity, lower hairiness and better fabric abrasion than sirospun.\textsuperscript{20, 22} The system is relatively to apply to existing spinning frames and should represent a lower cost alternative to some other offerings. The system has found some applications in woolen and worsted processing and there is active research to explore the possible use of this system for cotton fibers.

5 Open-end Spinning

It is clear from Table 1 that open-end spinning is now a mature technology with wide acceptance for certain types of yarns and markets. It is also apparent that open-end yarn processes really well through weaving and knitting with fiber shedding and yarn breaks significantly less than ring-spun yarn. The immediate problems identified with this technology are that the rotor diameter should be greater than the fiber length; there is a minimum number of fibers (typically about 100) required in the yarn section for stable spinning. The system is sensitive to impurities and trash. A further problem is that the aesthetics of open-end yarn are not as good as ring-spun yarn and it is often classified as having a harsh handle. Modifications to various machinery components have resulted in improvements in handle but there is still somewhat a stigma attached to the yarn. An additional problem is that open-end yarns and subsequent fabrics tend to be slightly weaker than their ring-spun counterparts and this can be critical if fabrics are to undergo severe finishing treatment. An example of this is the use of ‘stone-washing’ of denim where it is found preferable to use ring-spun yarns since the higher initial strength of the fabric yields a final fabric which is still acceptable after treatment.

The trends in machinery design are towards longer automated machines with up to 320 positions and to use smaller rotors running at high speeds (28mm diameter @ 150,000rpm). These are however aimed at finer yarn counts and one of the challenges of rotor spinning is to fully utilize the machines potential across a wide range of counts and fiber types. Indeed
there have been attempts to utilize other fibers such as wool on this system but these are only likely to meet with limited success because of radically different aesthetics produced by the coarser fibers.

6 Fasciated Yarns

Jet Spinning and Vortex Spinning—The concept of fasciated yarns was first proposed by DuPont but only became a commercial success for short staple fibers with the introduction of Murata Jet Spinning. Much research was carried out and the major advantages of this system were best realized while processing fine to medium count short staple polyester and polyester-rich blends. The reasons for this are well understood and attempts to process different types of fiber proved unsuccessful. An adaptation of the system utilizing two pairs of jets to create two-strand yarns, which were subsequently twisted together, met with very limited success, typically in the processing of mid-staple polyester blends. The more recent introduction of MVS (Murata Vortex Spinning) was intended to overcome some of the limitations of jet spinning and enable the satisfactory processing of fibers other than polyester at much higher speeds. The major difference between jet- and vortex-spun yarns is in the greater number of wrapper fibers present in the latter, which in parts has the appearance that is quite similar to a two-fold yarn (Fig. 10). While there are still refinements needed for this system particularly with respect to fiber preparation, minimization of fiber loss and yarn processing, there is great potential for this system because it was introduced commercially with a speed of 400 m/min and history has shown that successful machine tends to double in running speed during the first eight years following its introduction. The additional major benefit of this system is that it produces yarns with inherently low hairiness and this would be beneficial to the processing of fibers which usually result in fabrics that are prone to pilling.

7 Additional Technology

There has been a significant increase in on-line and off-line measuring, monitoring and testing equipments which can be utilized for quality monitoring, troubleshooting or research purposes. There is no doubt that yarn evaluation equipment has become more sophisticated and the use of apparatus such as Uster Tensiojet enables very rapid evaluation of the tensile characteristics of large quantities of yarn, and can provide a useful prediction of subsequent performance. Similarly, the latest regularity testers not only provide information on defects and with appropriate software the likely origins of the defects, but can additionally be linked to software and hardware which can give renditions of likely fabric appearance.

Improvements in the level of sophistication of low cost optical sensing devices has enabled greater applications of on-line sensing and while this can be used to detect, and if necessary respond to, major changes in yarn thickness, perhaps the most significant application of these devices is for the detection of foreign fibers. Several manufacturers now offer systems which can be incorporated into winding machines or, in some circumstances, spinning machines. In the former case, when coupled to spindle ID systems (see above), this provides a useful approach to potentially sourcing major defects.

There have also been many improvements in the tools available to spinning technologists and researchers and these largely center on sophisticated image processing systems. These enable much more rapid and dependable analysis of changes in processing parameters on yarn structure and properties. These are immensely useful while studying the mechanics of structures, or indeed proposing changes in existing or new technologies to effect improvements in particular properties. Of note is the recent availability of commercial DVI (Digital Volumetric Imaging) equipment which is being used to study fibrous structure from the automatic computer restructuring of data generated from
multiple sections taken of the product. Figure 11 shows an image of a yarn generated from this technique (obtained from images of a series of cross sections) plus a single fiber 'electronically extracted' from the yarn.\(^9\)

8 Future Developments

The idea of utilizing a centrifugal chamber to twist and collect the yarn is not new and indeed the Topham Box was a feature of early Rayon filament spinning lines. Other incursions into this type of spinning included the Greenbank Axispinner, which was designed for producing two-fold worsted yarns. Recently, there has been renewed interest in this technology and such a system was shown as a prototype at ITMA '99 by the Russian Company Techmaschexport. The advantage of such a system is that it would produce yarn of the same quality as ring-spun yarn but potentially at much higher speeds. There have been several patents awarded to other companies and no doubt that the major machinery makers have carried out studies on this technology. However, despite the potential advantages of such systems, which mainly center on the ability to produce a yarn with ring-spun quality at much higher speeds, it is unlikely that a commercial machine will be launched in the immediate future.

There are rumors of other systems being reinvestigated, including both friction spinning and electrostatic spinning but these systems have inherent problems that would make the production of yarn with acceptable quality at high speeds a non-starter. Additionally, it is not unrealistic to predict that some hybrid system may emerge, which will combine several technologies. There is no doubt, however, that any new system must offer significant benefits over existing technologies and the goal of 'ring-spun yarn properties' at very high production speeds is still the ultimate (but perhaps unrealistic?) goal of machinery makers and their potential customers.

A further aspect which must be considered is that while it may be more economic to spin very large lot sizes in semi-automated high speed spinning plants, this is only true if the yarn meets the demands of the customer (i.e. there is a ready market for the yarn!). In the US and Europe, there is a lot of interest in the development of niche markets, as a way of opting out of competing in the commodity market, which can be better served by less well developed countries. The problem this raises is that niche markets usually are transient and require rapid response (and change) and typically involve smaller lot sizes. Thus, the traditional philosophy of 'make it fast and make it cheap' becomes problematic since niche market products would not typically be found in this environment. There is thus a need for smaller efficient manufacturing machines capable of meeting the needs of this new climate.

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