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# A RULE-BASED EXPERT SYSTEM TO ESTABLISH THE LINKAGE BETWEEN YARN TWIST FACTOR AND END-USE

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***Abstract:***

*Optimising the technical and economic requirements to obtain a yarn with the appropriate twist level for sustained yarn quality and usage is of paramount importance. This paper describes the concepts and development of a rule-based expert system to establish the optimum linkage between the yarn twist factor and end-use of a yarn and determine the appropriate twist for the particular yarn.*

***Key words:***

*Yarn twist, yarn twist factor, end use, expert system*

## 1. Introduction

The simple answer to why we insert twist in a yarn is "to provide a yarn that in the widest and most thorough consideration is capable of producing fabric having the desired characteristics from a quality and performance aspect" (Lorenz, 1989). The twist in yarn adds strength to the yarn. In coming up with the optimum twist in a yarn, both technical and economic requirements must be taken into consideration. From a purely spinning economic point of view, the lowest twist possible is desired since it would maximise the production on the spinning machine. Nevertheless, such a yarn could prove difficult to handle and process in the subsequent processes (e.g. yarn preparation, weaving, knitting) since it may not have the necessary strength and leading to unacceptable machine stoppages and associated inefficiencies and costs. Twisting a yarn takes up machine time and the higher the twist the more machine time and costs are involved. From a technical point of view a minimum twist level is required to produce a yarn with the required tensile and abrasion characteristics. With a higher twist comes an improvement in the abrasion resistance, which is a desirable quality in weaving yarns. For weaving yarn higher twists are required for adequate strength of the yarn, while for knitting yarn (weft knitting in particular) a softer yarn and hence a lower twist is required to produce the relatively low level of cohesion required between fibres in the yarn. The longer the fibre the lower the twist that is required to produce the required fibre-to-fibre friction and cohesion, and associated yarn strength. High twist yarns are prone to snarling and heat setting (e.g. steam conditioning) sets the twist by releasing the torsional stresses in the yarn thereby minimising the snarling tendency (Balasubramanian, 1990). There is a need, therefore, to balance and optimise the positive and negative factors in order to come up with the ideal twist for a yarn that is required for any particular end-use. As a result there is a strong link between the yarn twist factor and the end-use of the yarn. An added dimension is whether a singles or folded yarn is to be used, and in the latter what the singles and folding twists should be.

The twist, (e.g. turns/centimetre) of different yarns cannot be compared if the yarn count varies from yarn to yarn. In such a case the twist factor is a far more meaningful measure of the degree of twist in the yarn of different counts (linear density). The twist factor is the tangent of the fibre alignment to the axis, arguably the degree of twist in yarn of different counts to be compared.

This paper describes the concept and structure of an expert system that establishes the link between the yarn twist factor and end-use of a yarn for the optimisation of the negative and positive factors associated with yarn twist. This system can be interrogated by textile manufacturers for information.

The remainder of this paper is structured in the following manner:

- Section 2 introduces concepts of the yarn twist and twist factor.
- Section 3 describes various yarn types.

- Section 4 describes related work.
- Section 5 describes the relationship between the yarn twist factor and end-use of the yarn.
- Section 6 describes the components of an expert systems architecture for establishing the link between yarn twist factor and end-use.
- Section 7 summarises the benefits of this architecture.

## 2. Yarn twist and the twist factor

Twist in a yarn can be defined in various ways. The simplest definition is, "Twist is a measure of spiral turns given to a yarn in order to hold the constituent fibres or threads together" (Tarafdar, 1988). Yarn twist is also defined as the spiral disposition of the components of a yarn, which is usually the result of the relative rotation of the extremities of the yarn (Johnson, 1981). The four attributes namely appearance, lustre, strength, elasticity, softness, handle, elongation and abrasion resistance are subject to the degree of twist or turns per unit length in single yarn, but in the folded (plied) yarns they are subject to a combination of direction and amount of twists in both the singles and folded yarn.

The amount of twist in a yarn can alter the handle of fabric made from it and this is an important consideration in determining the amount of twist required. If a crisp handle is required then the twist inserted should be relatively high, but if a soft handle is required a relatively lower twist is required. For example, a yarn intended for knitting would have a relatively low twist and would be quite unsuited as a weaving yarn. The difference in handle between a gabardine type of cloth compared with ordinary suiting is due almost entirely to the higher twist content of the gabardine yarn. An extreme example of excess twist is to be seen in crepe yarn, where the elasticity of the yarn is used to give a novelty effect to the cloth.

Twist is characterised by the number of turns (twists) per metre and by the direction of the twist (Ishida, 1977). The twist direction can be "Z twist", which runs upwards and to the right, formed by spinning the yarn in a clockwise direction or "S twist" formed by twisting the yarn counter-clockwise with the resulting twist runs upwards and to the left. The twist in the yarn for S and Z runs in the same direction as the diagonal used to form these letters. The amount of twist depends on the yarn linear density, and the level of twist (i.e. twist factor) required.

Yarn can be singles or ply, and the twist correspondingly singles and ply. Two or more single yarns can be twisted (plied or folded) together to form plied or folded yarn. The plying or folding is generally, but not always in the appropriate direction to that of the singles components. The twist direction of the majority of spun yarns is Z twist and the twist direction of their folding (plying) or final twist is S twist.

The amount of twists required also depends on the fineness and length of the fibre. The longer and/or finer the fibre the lower the twist required to produce the necessary cohesion (i.e. yarn strength and abrasion resistance). The required twist level and direction and the required number of strands are determined by both the yarn properties and the final application of the yarn. The twist, that is, the turns/metre (t.p.m.) depends on the yarn linear density (count) and the degree of twist (i.e. twist factor) derived.

The twist factor is the tangent of the fibre alignment to axis. The tex twist factor $\alpha_{tex}$ is defined as:

$$\alpha_{tex} = t\sqrt{T_i / 1000}$$

where:

$\alpha_{tex}$ is the tex twist factor,
$t$ = twist expressed in turns/metre (or turns/centimetre),
$T_i$ = the effective linear density (count) of the composite yarn expressed in tex.

The metric twist factor $\alpha_m$ is defined as:

$$\alpha_m = \frac{t}{\sqrt{N_m}}$$

where:

$N_m$ is the metric count (i.e. the number of 1000 metre lengths of yarn in a kilogram),
$t$ = twist expressed in turns/metre (or turns/centimetre).

The tex twist factor for knitting yarn is approximately 23, while that for weaving yarns is 3. Cotton has a relatively high twist factor due to the relatively short fibres, while wool has a relatively lower twist factor due to the long fibres. Table 1 shows the metric yarn twist factor ranges $\alpha_m$ for different wool blends.

**Table 1.** Yarn twist factor $\alpha_m$ ranges for wool blends.

| Yarn twist factor ranges for wool blends | |
|---|---|
| **Wool blend** | **Twist factor (metric count) ranges)** |
| Pure new wool – 2 fold yarn for flannel (semi-melton) | 70-80 |
| Pure new wool – normal 2 fold yarns | 80-85 |
| Pure new wool – single weft yarns | 65-70 |
| 55/45 polyester/wool (normal polyester) | 100-110 |
| 55/45 polyester/wool (anti-pilling) | 85-95 |
| 70/30 wool/regenerated cellulosic fibres | 75-85 |

## 3. Yarn type

A textile yarn is a fibre assembly of substantial length and relatively small cross-section of fibres and/or filaments with or without twist. There is no limit to the range of yarns that can be produced within the scope of staple, continuous filament, monofilament and multifilament yarns, single, plied and cabled yarns, and yarns with zero twist.

Spun staple fibre yarns consist of staple fibres assembled and bound together by various means (usually twist, but sometimes by adhesive and wrapper filaments) to produce the required characteristics such as strength, abrasion, handle, appearance, etc. Continuous filament yarns are produced by combining the required number of filaments and thickness of filaments simultaneously in one spinning operation. Continuous filament yarns with one filament are referred to as monofilaments and those with more than one as multifilament.

There is a vast range of staple fibre yarns. They can be classed by fibre length (e.g. short and long staple), by spinning system (e.g. ring and rotor), or by yarn construction (e.g. single, plied, cabled, multiple and fancy). Ring-spun yarns are produced on the ring and traveller system from a wide variety of fibre types. This is the most popular system of staple fibre yarn production, being able to utilise a wide range of fibre types, fibre finenesses and fibre lengths. The component fibres are twisted around each other to set up frictional forces between the fibres to impart strength to the yarn. Rotor spun yarns, like ring-spun yarns, consist of fibres bound together by twist. Rotor-spun yarns are generally only produced from short staple fibres. Generally, rotor yarns are more regular but weaker than comparable ring spun yarns. Because of their structure, they generally require higher twist than ring-spun yarn to achieve acceptable yarn properties. Very little wool is spun on rotor (OE) spinning machines.

Twistless yarns are produced from staple fibres where the consolidation of the fibres is by means of some form of adhesive. Fasciated yarns consist of a parallel bundle of fibres bound into a compact structure by surface wrappings at irregular intervals of staple fibres, air-jet yarns being a typical example. Wrap-spun yarns consist of parallel bundles of staple fibres bound into a compact structure by another yarn, usually continuous filament. They can be produced using both long and short staple fibres. Core-spun yarns are characterised by having a central core wrapped with staple fibres. These are produced in a single operation by feeding a yarn through the delivery rollers of a spinning frame, simultaneously with staple fibres. Rotor-spun (OE) yarns have twist inserted by a rotor rotating at a very high speed (up to 200 000 t.p.m.).
Self-twist yarns are two-ply yarns produced in a single operation. During manufacture each component is twisted in alternating directions in short segments. The two components are subsequently brought together in such a way that they twist around each other (self twist) to form the final yarn. Self-twist yarns are predominantly produced from long staple fibres. Friction-spun yarns are produced on spinning systems which use two rotating rollers to collect and twist individual fibres into a stable yarn structure.

Yarns with more than one strand are referred to as compound (plied or folded) yarns. A folded or plied yarn is one in which two or more single yarns are twisted together in a single operation, hence, 2-fold (2-ply), 3-fold (3-ply), 4-fold (4-ply), etc. Cabled yarns have two or more folded yarns twisted together in one or more operations. Folded and cabled yarns can be produced from staple yarns or continuous filament yarns or a combination of these.

There is a wide range of yarn types, such as fancy yarns, produced in small quantities which differ from the normal appearance of staple or continuous filament yarns. Fancy yarns differ from normal construction of single and folded yarns by having deliberately produced irregularities in their construction. They usually have a ground thread, around which the effect thread or fibres are twisted. Typical effects are knops, loops, snarls, slubs, etc. Chenille yarns are characterised by fibres projecting from the yarn around a central core of threads. Metallised yarns can be produced from aluminium sheets laminated between plastic film, the laminate structure is then cut into thin strips to form a flat ribbon yarn.

The range of filament yarns is not as diverse as that for spun staple fibre yarns. Flat continuous filament yarns are man-made continuous filament yarns that may be produced in either monofilament or multifilament form and do not have any crimp or bulk. In addition, the filaments may be matt (dull) or bright (lustrous) according to requirements. Standard filament yarns are known as 'flat" filament yarns in contrast to textured yarns. Textured yarns are man-made continuous filament yarns that have been modified by subsequent processing to introduce durable crimps, coils, loops or other distortions into the filaments, thereby improving their bulk and handle and comfort. There are a number of ways in which deformations can be introduced into the filaments, e.g. false twist, air jet, stuffer box, etc. Bicomponent yarns are produced from two components at the fibre extrusion stage. The components may be designed so that differential shrinkage occurs during the later process stages to introduce kinking, etc. Tape or split film yarns are produced from thin sheets of polymer cut into narrow strips or ribbons. The strips may be fibrillated to give an appearance similar to that of a flat filament yarn.

## 4. Related work

In textiles, rule-based expert systems have been applied in dyeing recipe determination (Convert, 1997 and 2000) and (Hussain, 2005), for the selection of fluorescent whiteners (Aspland, 1991), for three dimensional computer-aided intelligent design of garments (Liu, 2003), for fabric engineering (Ng, 1993) and (Behera, 2004) and the analysis of defects in textiles (Srinivasan, 1992). No known rule-based expert system has been applied to the determination of the link between yarn twist factor and end-use.

## 5. The flow of the yarn twist factor / end-use process

The turns per metre / inch (t.p.m / t.p.i) which is the actual twist in the yarn is determined by a combination of the twist factor that is required on the yarn and the gear settings on the spinning machine. Twist factor ranges for worsted spun yarns are shown in the Table 2 below (Hunter, 1978):

**Table 2.** Yarn twist factors for spun yarns (adapted from Hunter, 1978).

| Twist factor ranges for worsted yarns | | | |
|---|---|---|---|
| **Yarn** | **Tex twist factor $\alpha_{tex}$** | **Worsted twist factor $\alpha_w$** | **Metric twist factor $\alpha_m$** |
| Grey single yarn | 28 | 2.4 | 88 |
| Grey two-ply yarn | 27 | 2.3 | 85 |
| Dyed single yarn | 27.2 | 2.3 | 86 |
| Dyed two-ply yarn | 25.9 | 2.2 | 82 |
| Single grandrelle yarn | 27.8 | 2.4 | 88 |
| Two ply grandrelle yarn | 38.2 | 3.3 | 121 |
| Single knitting yarn | 19.0 | 1.6 | 60 |
| Two ply knitting yarn | 9.2 | 0.8 | 29 |
| Hand knitting yarn | 10.4 | 0.89 | 33 |

The flow of processes is given as follows:

- The yarn is identified as either knitting or weaving yarn, and for each of these yarns the particular type of yarn as described in Section 3 is identified.
- On the basis of the values of the relationships between the end-use of the yarn and twist factor, as shown in Table 2, the twist factor for a particular type of yarn is determined.
- On the basis of the required count of the yarn, the twist is calculated.

The twist factor for tex and metric values is calculated as shown in Section 2 of this paper.

A recommended range of yarn twist is calculated using the equation:

$$T = \left( \sqrt{\frac{1000}{tex}} \right) \alpha_m$$

where $T$ is turns per metre, $tex$ is the single yarn linear density in tex, $\alpha_m$ is the metric twisting factor.

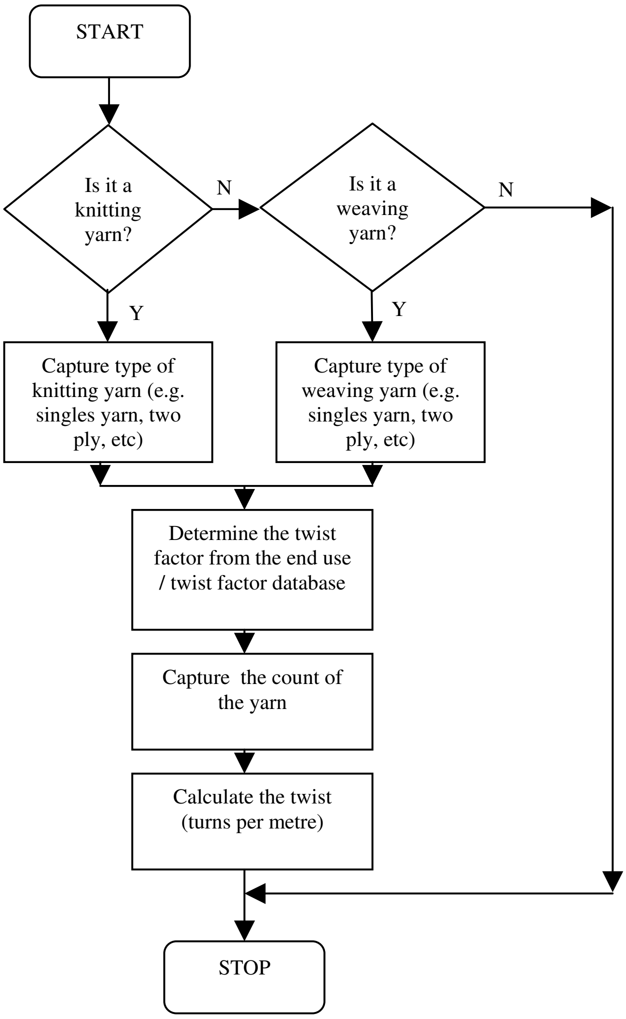


**Figure 1.** Flow of processes.

## 6. Architecture of the expert system

The components of any expert system include the knowledge base, inference engine, knowledge acquisition component and explanation system (Giarratano, 2003) and (Ignizio, 1991). The permanent knowledge of an expert system is stored in a knowledge base. It contains the information that the expert system uses to make decisions. This information presents expertise gained from top experts in the field. The purpose of the inference engine is to seek information and form relationships from the knowledge base and provide answers. It determines which rules will be applied to a given question and in what order by using information in the knowledge base. Most expert systems continue to evolve over time. New rules can be added to the knowledge base by using the knowledge acquisition subsystem. Another unique feature of an expert system is its ability to explain its advice or recommendations and even to justify why a certain action was recommended. The explanation and justification are done in a sub-system known as the explanation subsystem

Figure 2 shows the architecture of the expert system for the determination of the linkage between the yarn twist factor and end-use of the yarn.

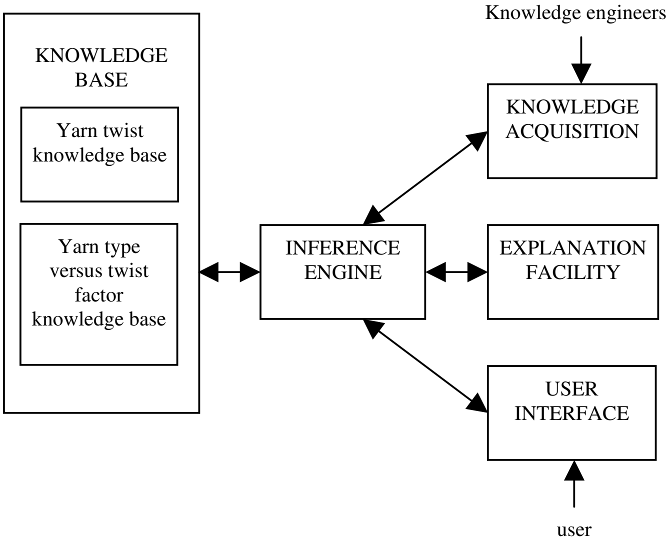


**Figure 2.** Expert system architecture.

### Knowledge base

The knowledge base of the proposed expert system consists of two parts: one that is related to the identification of the relationship between the yarn type and the twist factor as shown in Table 2, and the other that houses the formulae to calculate the twist from the yarn linear density (count) and the twist factor. Examples of rules from the knowledge base would be as follows:

GREY SINGLES YARN METHOD
IF grey singles yarn THEN
twist factor in tex units is 28
AND
twist factor in worsted units is 2.4
AND
twist factor in metric units is 88

TWO-PLY GRANDRELLE YARN METHOD
IF two-ply grandrelle yarn THEN
twist factor in tex units is 38.2
AND
twist factor in worsted units is 3.3
AND
twist factor in metric units is 121

The rules derived from the yarn twist formulae knowledge base can be:

YARN TWIST CALCULATION METHOD
IF the yarn linear density is tex
AND
the metric twist factor is $\alpha_m$

THEN the $twist(t.p.m) = \left( \sqrt{\frac{1000}{tex}} \right) \alpha_m$

**Inference engine**

An example of one of the rules in the inference engine is as follows:

IF for grey singles yarn
  IF to calculate yarn twist in tex
    IF yarn linear density is x
      THEN call GREY SINGLES YARN METHOD to determine
        twist factor in tex
      AND
        Call YARN TWIST CALCULATION METHOD to
        calculate twist

## 7. Analysis and conclusions

The need to optimise the technical and economic requirements in the determination of the appropriate twist for a yarn designed for a particular end-use has resulted in the need to look at the concepts and development of an expert system to establish the linkage between yarn twist factor and the end-use of a yarn. The quality of a yarn is determined by the twist factor, which in turn is defined by the fibre qualities and end-use of the yarn. The advantage of this architecture is that, with a shortage of expertise in the area, the expert system offers advice on the determination of the appropriate twist level in the place of the expert. The advice that it provides is more consistent. The added advantage is that no known expert system has been developed in this particular area. This is an interdisciplinary research that marries Textile Technology and Information Technology (IT).

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