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Spinning with the Hand Spindle

An Analysis of the Mechanics and its Implications on Yarn Quality

Abstract

A qualitative analysis of the process of yarn spinning with the hand spindle is proposed. The parameters influencing the characteristics of the yarn spun are identified: they are mainly defined by the fibre, the spindle and the spinner. Consequently the spindle whorl is not the unique factor determining the quality of the yarn spun with it, as has been suggested in the archaeological and ethnological literature.

Keywords: analysis, handspinning, spindle, whorl, moment, inertia, yarn, quality, archaeology.

Introduction

In the literature, a direct relation between the weight of the spindle whorl and the diameter of the yarn spun with it has been assumed (Bohnsack 1981; Crewe, 1998). Based on form, dimensions and weight of spindle whorls from Belize, Murray (1998, 159) concluded that “it is clear that the whorls were all used for the spinning of cotton, rather than maguey”. Loughran-Delahunt (1996) postulated a relation between yarn properties and the size and weight of spindle whorls, the fibre being spun and the type of thread being produced. Wright et al. (2012, 142) state that “there is a demonstrated correlation between the weight of spindle whorls, the fiber being spun, and the type of thread being produced”, and also that “identification and analysis of spindle whorls and their weights, would demonstrate varied fiber use and thread production.”

Dimensions, mass (‘weight’ in cited texts) and form of the spindle whorl determine its moment of inertia (MI). A higher MI yields a slower but longer rotation (Médard 2006, 107). Generally, the slower the rotation speed, the thicker and looser the yarn; the higher the rotation speed, the finer and more closed the yarn, independent of the lengths of the fibres used. These

indices were thought to allow a precise description of the relations between yarns and spindles (Médard 2006, 109). Therefore a direct relation was supposed between the yarn (kind of fibre, yarn thickness and strength) spun with a given spindle whorl, and the moment of inertia of that tool. But no proof for this idea has been given yet, mainly because of two reasons. First, the determination of the MI of a given spindle whorl is not always an easy task, especially for complicated forms. Recently, a method for its experimental measurement using a torsion pendulum (Chmielewski and Gardynski 2010), and formulas for calculating the MI (Verhecken 2010), have been published. But once the MI is known, it still has to be confirmed that, for a given spindle, a unique relation indeed exists between its MI and the properties of the yarns that can be spun with it.

Based on a restricted number of published and experimental data, Verhecken (2010, 268) could not confirm that supposed relation. The conclusion was: “More insight in the fundamental processes that occur during spinning might shed more light on the factors that determine the yarn characteristics”.

Kania followed up with a well-organised large-scale series of tests, spun at the occasion of Textil Forum



2009, 8-13 September in Eindhoven (Kania 2013). The results of these tests clearly show that there is no strict relation between the MI of the spindle and the properties of the yarn spun with it. Other factors are also involved in the spinning process; the most obvious being the person doing the spinning (here called 'the spinner'), and the properties of the fibre to be spun. This had not yet been studied in detail for hand spinning with the spindle whorl. An approach to that analysis is here presented.

Analysis of the spinning procedure

Kania (2013) gave a good description :

"To spin yarn using a hand-spindle, the spinner imparts rotation on the spindle which is typically hanging from the thread already spun. While the free-hanging spindle rotates, the spinner uses both hands to draft a controlled amount of fibre from the prepared fibre supply. The drafting process is done between the two hands, and twist is then allowed to enter the drafted fibres by releasing the pinch of the fingers of the lower hand on the thread, transforming the drafted fibres into yarn. Drafting is continued by bringing the lower hand back up close to the upper hand. The lower hand grips the yarn, thus stopping twist from travelling upwards into the fibre supply, and gently pulls downward for the next drafting cycle. The thread made in this manner has to be wound onto the spindle stick by hand, periodically interrupting the actual spinning process."

In the following, 'sliver' is an assemblage of fibres in rope form without twist, a 'roving' is the relatively fine fibrous strands used in the later or final processes of preparation for spinning (Anon. 1970), and 'yarn' here refers to the twisted single thread ready for use in weaving etc.

A yarn is characterised by the nature of the fibre, the fibre length, diameter, specific density; the amount of fibres in a yarn cross-section, the degree of packing of the fibres, the twist, expressed as twist angle (β) or as twist intensity ($\kappa = \text{tg}\beta$, or $Z = \kappa/(d.\pi)$, according to different authors), the yarn diameter (d), and the yarn count (T), expressed in Tex (gram per km yarn length), and breaking strength. Some of these parameters are interrelated.

The physics of the processes occurring during spinning is quite complicated. Formulas for a number of parameters have been proposed, based on industrial spinning research, but their mathematics is not easy (Kremenakova 2002). Therefore, in the

following treatment mainly qualitative relations will be used instead of quantitative formulae. An important number of factors influencing the quality of the yarn obtained can be identified and explained in the following:

The spindle: Consists of a spindle whorl with a central boring in which the spindle shaft, generally made of wood, is fixed. In archaeological sites, in most cases the shaft has disappeared; but the rotation properties of a spindle are mainly defined by the spindle whorl.

The roving: Starting from a sliver of fibres arranged in a partly parallel but overlapping position (by carding or combing), the spinner drafts them out to form a roving consisting of an intended *average number of fibres, overlapping* to an average degree. Since not all individual fibres from the same stock are equal in diameter and length, the fibres used have a given *range of diameters* and a *range of lengths*. The *density of the fibre material* also determines the *tex* of the yarn obtained.

Spindle rotation: From this bundle of fibres is manually drafted the material for a rove, that will be converted into yarn by the *twisting* caused by the *rotation of the spindle*. During twisting, each individual fibre is, to a certain extent depending on its radial position in the yarn, simultaneously submitted to bending and to torsion around its length axis. Moreover, the fibres are shifted in their position relative to each other. The amount of energy consumed during the twisting thus depends on the *bending* and *torsional properties* of the fibres and the *frictional properties* of their surface.

To that purpose, the spinner *activates* the spindle by giving it an amount of *energy* in some way, such as rotating the spindle shaft between thumb and forefinger (*flicking*), or by rolling the spindle shaft on the thigh. In both cases the spindle shaft (diameter d_s) is rolled over a length of surface L (thumb or thigh) in a given time t seconds: the shaft makes a number of rotations equal to $L/(\pi.d_s)$, each rotation equals π radians, so the angular velocity ω is $L/(d_s.t)$ rad/s. The energy thus given to the spindle equals $I.\omega^2/2$, where I stands for the MI (Verhecken 2010, 266). But as energy is consumed by the twisting of the fibres, the rotation will slow down and eventually stop, and then will start turning backward. The spinner will again activate the spindle before the rotation stops completely, when it still has a given *twist at the end of each activation period*.

It must be remarked that d_s can be different over the length of the shaft; thus d_s at the place where it is activated (flicked) is not indicated by the bore in the whorl, usually the only shaft dimension available to the archaeologist.



The above mainly applies to the freely hanging drop-spindle, but also to vertically or horizontally supported spindles, but in the latter cases extra energy is lost because of friction of the shaft with the support.

Twisting: The drafting action by the spinner, at a given *drafting speed* and for a given *drafting time*, together with the rotating movement of the spindle, produces the *twist* that forms a certain *length* of yarn. This length will be shorter than the rove length, because of the twisting during a given *twisting time*; this produces a *twist angle* β and a *twist intensity* κ (defined as the tangent of the twist angle β between the twist direction and the yarn axis). The rotation also brings more closely together the individual fibres in the yarn, and thus reduces the *diameter* and increases the *breaking strength* of the yarn. On the other hand, in the case of a pending spindle, this yarn length can get a slight relative *increase* owing to the weight of the spindle whorl, according to the *fibre slip* depending on its frictional properties. The yarn length can also be influenced by the *stress-strain properties* of the fibre, which can differ very greatly according to the fibre type (Morton and Hearle 1962, 287 fig. 13.22), but this can, at least partly, be reversed when the yarn is no longer under that strain.

The rotation is strongest immediately after each activation of the spindle, and gradually slows down as the activation energy is consumed by the twisting. Thus, the twist is not evenly distributed over the length of yarn spun from one or several drafts; but the twist is redistributed more evenly over that yarn length (Franzen 1954, 379) to a value called the *twist intensity* (κ), during which period the fibres are packed to the *fibre packing density* (μ).

The cop: The length of freshly made yarn is then wound around the spindle shaft, forming a generally conical *cop* (Cayne 1990), thus increasing the total weight of the spindle as the cop is added to, and consequently also the MI of the spindle, resulting in a *slower rotation* for a same activation energy. This increase in weight also will produce an *extra elongation* of the yarn which is still in the spinning phase, and thus a growing compaction of the fibres in the yarn cross-section. So, these parameters will change during spinning, unless the spinner (intentionally or intuitively) compensates for these effects.

When the spinner judges that the amount of cop is enough (because the spindle is 'full', or spinning the intended yarn quality becomes too difficult, spinning is stopped and the cop is taken from the spindle. Then a new spinning cycle can be started with the 'empty' spindle under parameters markedly different from the situation just before.

The yarn: Since the parameter *yarn count*, expressed in *tex*, is always determined on relatively large yarn lengths, this averages out variations in that value along the yarn. These variations can be important: drop spindle spun woollen yarns typically vary from one-third to three times the average *tex* (Cooke and El-Gamal 1990, 71), and the yarn-breaking strength depends on its thinnest parts. The yarn diameter must be measured at many places, and then averaged.

The yarn count can also depend on the spinning technique used (drop-spindle versus supported spindle) since a very thin yarn (depending on the length and surface properties of the fibre) cannot support the weight of a heavy spindle. But it may be difficult to judge the spinning technique used at archaeological sites, unless spinning-bowls can be identified clearly there.

The spinner: Obviously the experience and skill of the spinner is of great importance for the quality of the yarn produced. Even when the same spinner works with the same fibres, the yarns obtained will not be completely identical: they will show differences that are not accounted for in this study but which can be measured and statistically evaluated. However, such close scrutiny is severely problematic in archaeological contexts.

Results

From the above description it is clear that the parameters of importance for spinning depend on: a) several properties of the fibre used; b) the characters of the spindle used: mainly the spindle whorl; c) input given, intuitively or based on experience, by the spinner; d) values derived from combinations of all the above.

Some of the parameters are basic physical values such as length, mass, speed; others are derived from these basic values. Some of the relations governing fundamental yarn parameters such as yarn count (T), twist intensity (κ), packing density (μ), and diameter (d) have been quantitatively studied in industrial contexts (Kremenakova 2002); but other parameters have not yet been fully studied. In these latter cases, when values cannot be calculated (yet), the dependency can be established qualitatively by straightforward reasoning.

Table 1 lists the parameters influencing the yarn quality, and indicates whether they are dependent on the spinner, the spindle, the fibre, or on a combination of some of these factors. In number, the spindle parameters form only a minor part; but the relative amount to which every parameter influences the properties of the yarn cannot be derived in a simple



Table 1. The parameters influencing the yarn quality, and the factors by which they are defined.

	Parameter	Symbol	Unit	Defined by			Derived	
				Spinner	Spindle	Fibre	from	Relation
1	Activation energy	E	joule	x	x		x	$E=I \omega^2/2$
2	Spindle mass		g		x			
3	MI spindle	I	g cm ²		x		x	2 form-dependent
4	Cop mass		g	x		x	x	
5	MI cop	I	g cm ²	x				6 form-dependent
6	Number of fibres in draft		n	x				
7	Mean fibre length	lf	mm			x		
8	Mean fibre diameter	df	mm			x		
9	Fibre density	ρ	g/cm ³			x		
10	Fibre count	dT	g/kg			x		decitex
11	Fibre bending properties					x		
12	Fibre torsion properties					x		
13	Fibre friction properties					x		
14	Fibre stress-strain propert.					x		
15	Rotation speed at start		RPS	x	x		x	$\omega=\sqrt{(2E/1)}$
16	Drafting time		sec	x				
17	Length per draft		cm	x				
18	Drafting speed		cm/sec	x			x	16, 17
19	Twist equilibration time		sec	x			x	15, 24
20	Twist at end of activation	Z	m-1	x				twists /m
21	Twist intensity	κ	none				x	20, 25 $\kappa= \text{tg}\beta = \pi d Z$
22	Twist angle	β	°				x	21
23	Draft-to-yarn shortening		%	x			x	21
24	Rotation speed at stop		RPS	x		x	x	15
25	Total nr of rotations at stop		none	x			x	15, 20, 24
26	Weight-induced elongation		%		x	x	x	13, 14
27	Yarn count	T	g/km				x	tex
28	Yarn diameter	d	mm				x	6, 8, 21
29	Yarn density	γ	g/cm ³			x	x	9, 30
30	Fibre packing density	μ	none				x	21, 29, 9 $\mu= \gamma/\rho$



way. In studies on archaeological spindle whorls, the influence of the spinner is generally not mentioned, obviously by lack of data.

Conclusion

The important parameters for the action of yarn spinning with the manual spindle were identified, and found to be dependent on the characteristics of the spindle whorl, the fibre spun, and on the actions of the spinner. This is shown here based on a qualitative analysis. Consequently, it must be concluded that the properties of the individual spindle whorl used do not uniquely determine the properties of the yarn spun with that spindle whorl. This implies that it is not possible to deduce the properties of the yarn that had been spun with spindle whorls of known MI, found at archaeological sites. Only very wide ranges of yarn properties can intuitively be related to coarse groups of spindle whorls, as illustrated e.g. by the incompatibility of a very thin yarn and a heavy spindle (cfr. the yarn).

Acknowledgements

Thanks are due to Katrin Kania for permission to cite from work before publication.

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