



## The Technology of Terry Towel Production

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### ABSTRACT

*The bath textiles segment in the US home textiles market has increased by 2.8% in sales to \$3.7 billion, 51% of which is towels at a value of \$1.88 billion (Corral, 2005). In this study the terry towel is investigated from fiber content through the woven construction to dyeing and finishing. The technologies used in the delivery of a final product to market are explained. New trends and technological developments occurring in the towel market and production processes are explored. In addition to changes in style, new fibers, new yarns, and new fabrications are also a focal point in the world's towel market (Leizens, 2001).*

*Terry towels are often very complex with yarns of different types and colors, in combination with various loop pile and flat structures. Towels are subject to changing fashions, and the market is constantly demanding new designs with improved fabric characteristics important to the consumer such as softness and absorbency. In satisfying these requirements, the content and structure of terry towels are critical decisions determining the resulting quality.*

*This review of the terry characteristics, specifications, production, and performance will be of interest to academicians and industry personnel as a basis for understanding the steps in producing a high quality woven terry fabric.*

*Keywords: Terry weaving, towel*

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### 1. INTRODUCTION

According to the Cotton Incorporated Lifestyle Monitor<sup>TM</sup> Home Fabrics Study, 91% of the female consumers polled said they prefer thicker towels, and 94% said they like their towels as soft as possible. The two most important factors they cite when purchasing a bath towel are softness (83%) and absorbency (82%). "Nothing feels more luxurious and comforting than

wrapping myself or one of my children in a thick, soft, fluffy towel after bathing" says Lindsey, a healthcare administrator and mother of two living in Boston, MA. Consumers also pay an average of \$7 for a bath towel, and their households own and use an average of 15 bath towels and 79% of them wash the towel before first use (Cotton Inc, 2003).

In the U.S. textile market, the bath category proved to be a growing segment in home textiles during 2004, gaining 2.8% in sales to \$3.7 billion, 51% of which is towels at \$1.881 billion (Corral, 2005).

While these numbers explain the retail sales of towels, the production and shipment quantities and values of U.S. for years 2002 to 2004 are shown in Table 1. In 2004, the value of terry towel shipments from the U.S. was \$715,575,000.

**Table 1 US Terry Towel Production and Shipment Figures for 2002 to 2004 (US Census Bureau, 2005)**

<u>Quarter and year</u>	<u>Production</u> Quantity Thousand dozen	<u>Shipments</u>	
		Quantity Thousand dozen	Value \$1000
<b>2004</b>			
Total	20,822	21,406	715,575
Q4	4,493	4,669	162,708
Q3	5,227	5,354	180,124
Q2	5,706	5,778	190,762
Q1	5,396	5,605	181,981
<b>2003</b>			
Total	25,346	26,370	822,099
<b>2002</b>			
Total	29,635	29,550	946,114

The U.S. import figures of terry woven towels and washcloths for 2004 are shown in Table 2. The total quantity of imported

terry woven towels and washcloths to U.S. is 131,837,000 dozens and its value is \$1,359 billion dollars in 2004.

**Table 2 US Import Figures of Woven Terry Towels in the first quarter of 2005 and four quarters of 2004 ( US Census Bureau, 2005-2005b)**

<u>Product code</u>	<u>Product description</u>	<u>Imports for consumption</u>	
		Quantity thousand dozen	Value \$1000
3141295010, 313210B110, R141 pt.	Terry woven towels and washcloths		
<b>2005</b>			
Q1		33,350	399,921
<b>2004</b>			
Total		131,837	1,358,951
Q4		34,436	339,745
Q3		34,436	309,290
Q2		32,952	347,046
Q1		32,971	362,870

Table 3 shows the production and shipment figures of terry towels according to the end uses. While the washcloth had the first rank in quantity base, 13,300,000 dozen washcloths out of 20,822,000 dozen finished towels of all purposes, bath towels had the biggest share in total value of towel market, \$441,875,000 out of total \$715,575,000 in 2004.

In the first quarter of 2005, 33,350,000 dozens of finished towels were imported to the U.S. for consumption with the value of \$399,921,000 while, 5,794,000 dozen finished towels are produced in the U.S.

The percent of import to domestic manufacturer's shipments is 575.6% in quantity basis, while the percent of export to domestic manufacturer's shipments is 5.4% again in quantity basis. Towel consumption is 38,834,000 dozens for 2005's first quarter in US (US Census Bureau, 2005). Domestic production can not compete with the very low labor costs in the developing countries. That is the reason why a very big percentage of towels in the U.S. market place are imported, very similar to most textile and apparel products (Cassill, 2005).

**Table 3 Production and Shipment Figures of Towels according to their end uses (US Census Bureau, 2005)**

Product Description	2004		
	Production	Shipments	
	Quantity thousand dozen	Quantity thousand dozen	Value \$1000
Finished towels	20,822	21,406	715,575
By end use:			
Kitchen	(D)*	(D)	(D)
Bath	10,827	11,226	441,875
Hand, face, guest, and fingertip	7,995	7,975	171,303
Bath/tub mats	(D)	(D)	(D)
All other	(D)	(D)	(D)
Washcloths	13,300	12,724	111,882
*D The information was not disclosed to protect the privacy of the companies that produce these items.			

This data which contains the volume of the towel market reveals the importance of the technology required for terry towel production to address the needs of the market. In the following sections, a description of terry towels and the technology of terry towel production steps such as spinning, weaving, dyeing-finishing and sewing and cutting steps are explained.

## 2. DESCRIPTION of TERRY TOWELS

### 2. 1. Terry Towel

A terry towel is described as a textile product which is made with loop pile on one or both sides generally covering the entire surface or forming

strips, checks, or other patterns (with end hems or fringes and side hems or selvages) (ASTM D 123, 2003).

## 2.2. The History of Terry Weaving

The name “terry” comes from the French word “tirer”, which means to pull out, referring to the pile loops which were pulled out by hand to make absorbent traditional Turkish toweling. Latin “vellus”, meaning hair, has the derivation “velour”, which is the toweling with cut loops (Humpries, 2004b).

In research conducted on terry weaving by the Manchester Textile Institute, it was concluded that original terry weaving was likely the result of defective weaving. The research indicates that this development occurred in Turkey, probably in Bursa City, one of the major traditional textile centers in Turkey. Terry weaving construction is considered a later development in the evolution of woven fabrics. Terry toweling is still known as

‘Turk Fabric’, ‘Turkish Toweling’ or ‘Turkish Terry’ (Bozgeyik, 1991).

## 2.3 The Parts of a Conventional Terry Towel

A woven towel consists of five parts. These are the pile area, fringes, beginning and end part, selvedge, and border. Every towel does not have to contain all of these parts. The pile area is considered the toweling part of the towel. Fringes are tied or untied tasseled parts of ground warps and pile warps which are left unwoven at the beginning and the end edges of the towel. The beginning and end sections are the tightly woven areas of a towel which come before or after the pile fabric part and prevent this pile area from unraveling. They are woven without pile loops, in a flat weave construction. The selvedge contains fewer number of warp ends than the pile area, for example 90 comparing to 4000 total warp ends, woven without pile as a flat weave and has the purpose to reinforce the towel sides (Acar, 2004). These parts are shown in Figure 1.

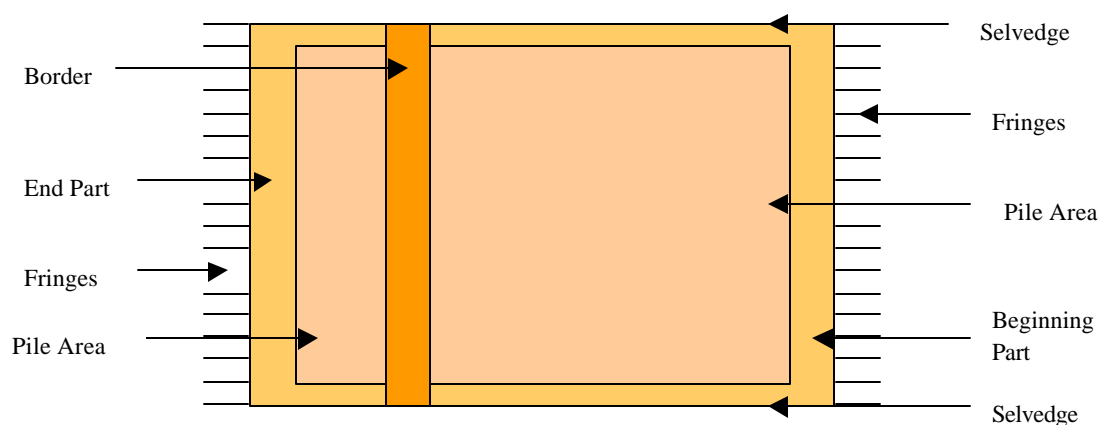


Figure 1. Parts of a Towel

## 2.4 Classification of Terry Towels

The classification of towels can be made according to weight, production, pile presence on fabric surfaces, pile formation, pile structure, and finishing. These classifications are shown in Table 4.

In velour towels pile loops on one side of the fabric are sheared in order to give a smooth cut velvet appearance. Uncut loops give the best absorbency, whereas velour gives a luxurious velvety hand (Humpries, 2004b). The explanation of shearing and brushing is given in Section 3.3, and finishing in Section 3.4.

A towel with appliqués is embellished with additional pieces of decorative fabric in a motif which is stitched onto the towel (Humpries, 2004).

Two-pick terry towels which were woven for bathrobe end-use have lost their importance today due to instability of the loops (Acar, 2004). Five or more pick terry towels are rarely produced because they need to be beaten for each pile twice. Now, the most prevalent towels are three and four-pick terry towels (TS 629, 1991). The explanation of pick numbers for terry weaves is given in Section 2.5.2.

As one sided pile toweling has low water absorbing capacity, it is only used for special purposes such as a limited number of bathrobes. Furthermore weaving one sided pile terry with few or no defects is difficult. In two sided pile terry both sides are covered with pile, whereas all the irregularities are visible in one sided terry fabric as one side is bare, without pile.

Towels are divided into groups according to end use and size as bath towels, hand towels, face towels, fingertip towels, kitchen towels and washcloths (US Census Bureau, 2005).

**Table 4 Classification of Terry Towels according to Weight, Production Style, Finishing, Weft Count Per Pile Loop and Pile Presence on Fabric Surfaces**

<u>Weight</u>	<u>Production</u>	<u>Finishing</u>	<u>Weft Pick Count per Pile Loop</u>	<u>Pile Presence on Fabric Surfaces</u>
<b>Very heavy (&gt;550 g/m<sup>2</sup>)</b>	<b>Woven</b>	<b>Velour Towel</b>	<b>Two-pick Terry</b>	<b>One side pile</b>
<b>Heavy (450-550 g/m<sup>2</sup>)</b>	<b>Weft Knitted</b>	<b>Printed Towel</b>	<b>Three -pick Terry</b>	<b>Both sides pile</b>
<b>Medium (350 -450 g/m<sup>2</sup>)</b>	<b>Warp Knitted</b>	<b>Towel with Embroidery</b>	<b>Four-pick Terry</b>	
<b>Light (250-350 g/m<sup>2</sup>)</b>		<b>Towel with appliqués</b>	<b>Five -pick Terry</b>	
			<b>Six-pick Terry</b>	
			<b>Seven (or more)-pick Terry</b>	

## 2.5 Structure of a Towel

### 2.5.1 Contents of a Towel

#### 2.5.1.1 Fibers used in Towels

According to Acar, the required properties of yarns which are used in terry towels are high absorbency (ASTM D 4772, 2002), high wet strength, ability to

dye well, good colorfastness (ASTM D 5433 00, 2000), wash-ability, soft hand, hypoallergenic, low cost, and easy availability. Yarns made of cotton fibers can provide these properties most effectively (Mohants, Misra and Drzal, 2005).

## Cotton Fibers

Cotton fibers consist of the unicellular seed hairs of the bolls of the cotton plant, the *Gossypium* plant (Mohants, Misra and Drzal, 2005). The chemical composition of typical cotton fiber is as follows: 94.0% of dry weight is cellulose, 1.3% is protein, 1.2% is pectic substance, 0.6% is wax, 1.2% is ash and 4% is other substances (Kaplan, 2001).

Absorbency refers to a cotton fabric's ability to remove liquid water from the skin as in a towel (Cotton Inc, 2005). Cotton is hydrophilic; it wets easily, and can hold much more water than synthetic fibers can. Cotton releases a considerable amount of heat when absorbing moisture, but it dries slowly (Mohants, Misra and Drzal, 2005). It is not only the amount of water held that is most important, but the speed with which moisture is removed from the body. The size and distribution of the pores, and capillaries, between and within cotton fibers are uniquely suited for this purpose (Cotton Inc, 2005).

Wet strength is one of the crucial properties required in towels, as they are most likely to remain wet as compared to other home textiles. Cotton is stable in water and its wet tenacity is higher than its dry tenacity. The toughness and initial modulus of cotton are lower compared to hemp fibers, whereas its flexibility and its elastic recovery are higher. (Mohants, Misra and Drzal, 2005).

Cotton is a natural fiber and considered hypoallergenic. This means cotton has a low tendency to cause allergic reactions. It also does not cause skin irritation and can be sterilized. The microbial resistance of

cotton is low, but the fibers are highly resistant to moth and beetle damage. The microbial resistance can be improved by antimicrobial finishing (Mohants, Misra and Drzal, 2005). Cotton uses in the medical institutional area are well known for their hypoallergenic characteristic and sterilize-ability. Cotton fabrics are often recommended for persons having skin allergies. Cotton sanitary products and cosmetic aids are promoted for their health benefits. Cotton towels, bedding and baby clothes have all been promoted on the basis of the hypoallergenic nature of cotton (Cotton Inc, 2005). Moreover cotton's resistance to high temperatures of water makes cotton easy to be cleaned as it can be boiled (Mohants, Misra and Drzal, 2005).

Cotton fibers are the backbone of the textile trade of the world (Mohants, Misra and Drzal, 2005). It has the highest production and consumption figures among the other natural fibers. It has easy availability as it is grown in more than seventy countries of the world (Anarjit, 1999). In the year 2003, 38.40% of the world fiber production was cotton (Cassill, 2005). One other reason cotton is used for toweling is it is the most economical fiber among the natural fibers (Humpries, 2004).

Shorter staple cotton fibers are generally used in towels because fine yarn counts are not required (Chewning, 2004). According to Table 5, the cotton fibers which are used in towels have relatively low fiber length, relatively low fiber strength, relatively low maturity ratio. The micronaire range can be said to be in the middle range (Anarjit, 1999).

**Table 5 Ranges of Cotton Fiber Properties which are used in Toweling Fabrics according to US Cotton Fiber Chart 1995 (Anarjit, 1999)**

Fabric Type	Fiber Length (inch)	Fiber Strength (g/tex)	Micronaire	Maturity Ratio
Toweling	0.93-1.10	20-32	3.5-4.9	0.80-0.90

## Other fibers

More and more towels are being produced from fibers other than cotton such as Modal®, bamboo, seaweed, Lyocel® and now soybean, corn and other fibers (SanFilippo, 2005). Tri-blend bamboo, silk and cotton blend is also beginning to be used in towels (Corral, 2005).

Bamboo may be the next premium fiber other than high quality cotton fibers. Such as Egyptian, Pima and Supima qualities, bamboo can be used in towels because of its softness, luster, antibacterial properties and greater absorbency. However, it has yet to gain acceptance on a large scale (SanFilippo, 2005).

Flax is also among the natural – hydrophilic fibers of cellulose like cotton (Ali, Ali and Speight; 2005). The fiber is termed flax, while the fabric made of flax it is called linen. Flax has better dry strength than cotton, and like cotton it gets 25% stronger when wet. It absorbs more moisture, and it wicks. It is longer, smoother, and more lustrous than cotton. However it is not used commonly in towels as it has been limited in supply, and it is expensive because of the long processing and intense labor it needs to be turned into a yarn (Humpries, 2004). Although uncommon, flax towels have a place in the specialty market. In the year 2004, totally 1,949,421 flax towels were imported to the U.S., which stands for 0.35% of the total towel import of the U.S. (Otexa, 2005).

Micro-fiber towels are also pushing into the ultra-touch/high absorbency arena with a manmade synthetic product constructed primarily from a blend of polyester and nylon with polyamide. Through a chemical process, the polyester, nylon and the polyamide are bonded. The result is a cloth that goes through another process to split its fiber into smaller “micro” fibers, creating tiny channels. Micro fiber towels can absorb 5 to 7 times their weight in water. Like cotton, micro-fiber towels are available in various colors

and weaves, such as waffle, cut terry and loop terry, with various patterns and in various weights. The heavier the micro-fiber towel, the more water it can absorb. Compared to ring spun cotton, micro-fiber is said to be more absorbent. Several companies are experimenting in combining micro-fiber with cotton to make it softer, give a better hand and perhaps make it more appealing to those who are unsure about having a synthetic towel product (Lazaro, 2003).

### 2.5.1.2 Yarns which are used in Towels

In a terry towel there are four groups of yarn. These four groups are the pile warp, ground warp, weft (filling), and border weft (Acar, 2004).

#### *Pile Warp*

One hundred percent cotton yarns, carded or combed, in sizes of 16/1, 20/1 Ne counts, 240-255 turns/meter twist, are most commonly used. The use of cotton-rayon blends has diminished, because 100% cotton provides a more pleasing hand and texture than the blends (Humpries, 2004).

When high quality is required, two or more ply yarns are used. In this case absorbency increases, and the fabric gains resistance to pile lay. The use of two-ply yarns is also on the increase as it improves visual appearance (SanFilippo, 2005). Plied yarns are used to form upright loops in classic terry, whereas single yarns are used to form spiral loops in fashion terry known as milled or fulled goods. In Figure 2, two types of loops are shown. (I) is an upright loop and (II) is a spiral loop. In the first type of classic terry patterns are usually created by employing dyed yarns; while towels of the fashion type are mainly piece dyed or printed (Adanur, 2001). In general bulkier and absorbent yarns are used for both types of towels. In real Turkish-toweling, the pile-loops generally consists of a more highly-twisted yarn which, while very absorbent, are quite abrasive, thus actively

stimulating the skin during drying (Donaldson, 2003).

Rotor spun yarns are also used in pile warps (Rozelle, 1996). Low twist cotton

yarns are also used because of the high absorbency and the nice hand they give to the towel (SanFilippo, 2005).

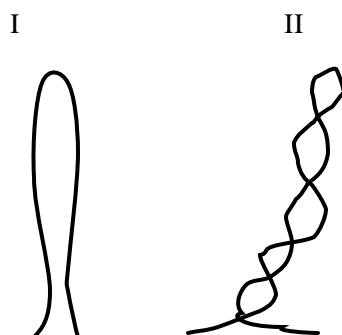


Figure 2 Two Types of Loops

### Ground Warp

Carded yarns of 20/2, or 24/2 Ne count with 550 turns/meter twist, and of 100% cotton are commonly used for ground warp ends (Acar, 2004). Two ply yarns are preferred because the ground warp endures the highest tension during weaving. It is common to use a yarn of cotton/polyester blend for greater strength (Donaldson, 2003). Rotor spun yarns are also used in ground warps (Rozelle, 1996).

### Weft

Carded yarns of 16/1, or 20/1 Ne counts with 240 – 255 turns/meter twist, 100% cotton are used usually for weft or filling picks (Acar, 2004). Rotor spun yarns are also used in wefts (Rozelle, 1996).

### Border Weft

Premium or high end hand towels have complex borders with fancy weaves and use a very wide range of filling yarns (Dornier, 2003). Decorative, shiny and bulky yarns of rayon, viscose, polyester, chenille, or mercerized cotton are used at different yarn sizes. Novelty types of

yarns may be used as a feature of design (Acar, 2004).

### 2.5.2 Construction

Terry towels are woven as 2, 3, 4, 5 or more pick terry weaves. The most common type is 3-pick terry toweling. The cross section of a toweling through the warp is shown in Figure 3.

Warps are divided into two systems as shown in Figure 3, pile warps and ground warps, whereas wefts consist of only one system. In basic Turkish Toweling, front side and back side pile warps and 1st and 2nd ground warp ends form a 2/1 rib weave with each other. The rib weave which is formed by the pile warps is one pick ahead of the rib weave which is formed by ground warp ends. Warps are ordered throughout the fabric width 1:1 or 2:2 pile and ground warps. In 1:1 warp order each ground warp end is followed by a pile warp end while in 2:2 warp order each two ground warp ends are followed by two pile warp ends. In Figures 3a and 3b, the weave notation of 3 weft pile basic Turkish toweling is given in 1:1 and 2:2 warp order (Baser, 2004).



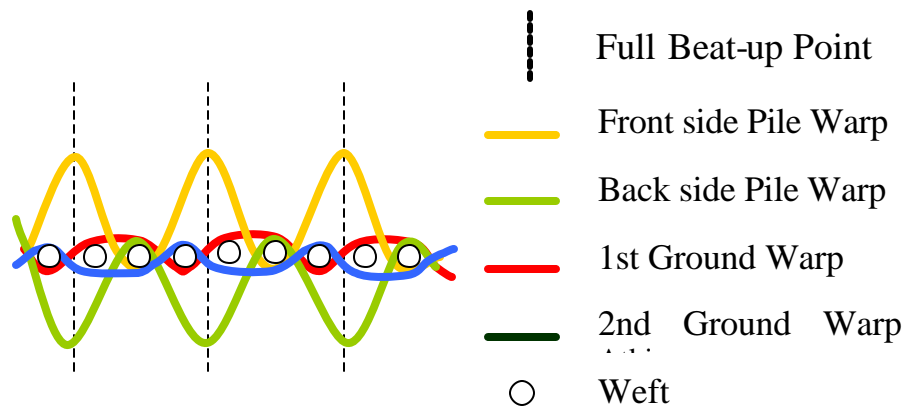


Figure 3 The cross-section of a towel through the warp (Acar, 2004)

As is seen from the weave diagrams in Figures 4a and 4b, the shedding of the ground warps are not synchronized with that of the pile warps. By this, the number of interlacings throughout the warp increases, and this strengthens the fabric (Bozgeyik, 1991).

As it has been mentioned before terry towels can have pile loops on one or both faces. Different types of terry weaves which have pile on one face and both faces are shown in Appendix-1.

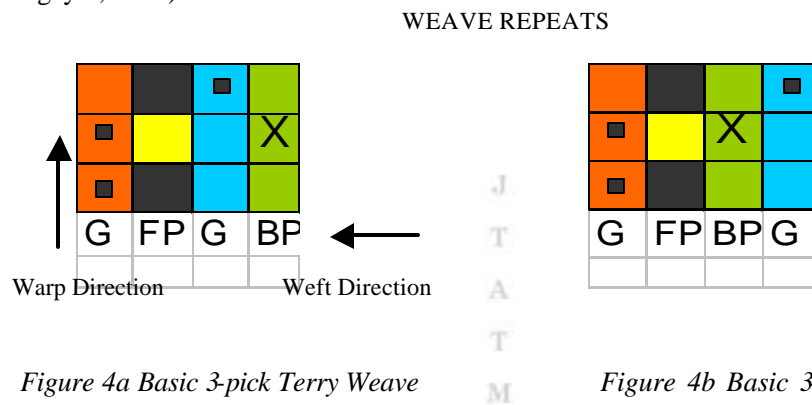


Figure 4a Basic 3-pick Terry Weave in 1:1 Warp Order (Baser, 2004)

Figure 4b Basic 3-Pick Terry Weave in 2:2 Warp Order (Baser, 2004)

In Figure 4a and 4b;

G: Ground Warp

FP: Front Face Pile Warp

BP: Back Face Pile Warp

Little block: Ground warp is over the weft

Shaded: Front Face Pile Warp is raised over the weft

X: Back Face Pile Warp is raised over the weft

Empty space: Warp is lowered behind the weft (Baser, 2004).

The weft count used for toweling is between 15 and 25 picks/cm. And warp count is between 20 and 30 ends/cm (Acar, 2004). During the weaving of borders, the weft count is increased 3 to 6 times the density in the pile areas (Dornier, 2003).

Pile/ground ratio is described as the length of pile warp per unit length of fabric in the warp direction. A practical way to find out this ratio is done by measuring a 10 cm length of toweling in the warp direction, then cut the pile warp from either ends of the measured length and measure the total length of the removed pile end per 10 cm length of fabric. Pile warp length per 10 cm fabric is usually between 20-100 cm. This ratio has a direct effect on the fabric weight and thickness. As the ratio increases, the weight and the thickness of the terry fabric increases (TSE629, 1991).

## 2.6 Physical Properties of a Towel

### *Absorbency*

High absorbency can be achieved in a towel by increasing the surface area with pile yarns and using cotton yarns with twists lower than the ground warps (Cotton Inc, 2005).

### *Heat Insulation*

Pile yarns make the fabric thicker and give the fabric a high level of heat insulation. Moreover cotton fibers which are used in towels are naturally convoluted and bulked. This serves to trap air within the fabric structure. The air contained between fibers and within them provides thermal insulation. These convolutions

plus the tapered fiber ends also hold the fabric away from the skin, adding to the amount of air trapped and contribution to heat insulation (Cotton Inc, 2005). According to the results of an experiment which was carried out by Morooka, Nakamura and Morooka, dry heat loss of toweling fabrics was found to be lower than that of common cotton fabrics on the market. However dry heat loss was found to be higher than is expected from the thickness and apparent density (Morooka, Nakamura and Morooka, 2003).

### *Crease Resistance*

Pile yarns give the fabric a third dimension which makes the fabric nearly uncreasable.

### *Dullness*

The pile loops form a very rough textured surface, thus giving the fabric a dull appearance. This situation is true for only un-sheared toweling. Velour toweling has an appearance even brighter than that of a traditional fabric (Humpries, 2004b). The cut pile forms a very smooth surface and reflects light evenly. The pile direction on both velour and uncut terry fabric also has an effect on the color appearance. This is related to the reflection angle which changes with the pile direction. This effect is more obvious in velour terry towels. When the pile direction is laid downwards, the fabric offers a smoother surface for light and so appears more lustrous. If the pile is erect, the color is richer because more of the fabric (and color) is visible while looking into the depth of pile loops (Price, Cohen and Johnson, 1999).

Woven terry fabric performance requirements are given in Appendix-2.

## 2.7 Quality Defects which are Common in Terry Towels

The defects which can be found in toweling are shown on Table 6:

**Table 6 Quality Defects which are seen on terry woven towels (TS 629, 1991).**

<u>Weaving Defects</u>	<u>Wet Processing Defects</u>	<u>Sewing Defects</u>	<u>General Defects</u>
Missing Pile.	Uneven dyeing	Low Stitch number	Crushed pile
Missing filling pick.	Offshade	Widths of parts are out of tolerance	Stain
Thin or thick filling pick.	Print defect	Missing or faulty stitch	Cut, hole, tear or burst
Beginning or end part is missing	Design Defect	Un-reinforced stitching on ends	Any dimension out of standard
Side part is missing	Noxious or offensive odors		
Stop mark.			
Reed mark.			
Wavy selvedge.			
Dense Weft			

Dense weft defect means that the higher density of the border part is used by mistake in the pile part (TS 629, 1991).

Out of tolerance parts' widths mean the total width and the folded-in width of the beginning, end and side parts are lower than required by the standard (TSE, 1991).

## 3. TECHNOLOGY of TERRY TOWEL PRODUCTION

Terry towel production processes include spinning, weaving, dyeing and finishing, and cutting as general steps. Shearing and embroidery are also regarded as necessary sub steps to obtain the final product of a terry woven towel.

### 3.1. Spinning

The cotton yarns which are used in terry towels are produced by either ring spinning or open-end spinning (Lord, 2003) and by other techniques which are specially developed for producing pile warp yarns for towels (Leizens, 2005).

#### 3.1.1 Ring Spinning

The principle of ring spinning is first blending the fibers, opening them and arranging as much as possible parallel to each other. Second is to give the fibers a twist in order to increase the friction forces between the fibers and assure they stay as a yarn and draw them to the desired size. These are achieved in several steps as follows (Lord, 2003).

### *Carding and Prior Processes*

All staple fibers are carded during conventional yarn processing. After opening of the cotton bales, loose fiber is blended and formed into a picker lap, which goes into the carding machine. Here, fine bent wires on revolving cylinders pull the fibers apart, remove waste and begin to arrange the fibers enough that they can be spun into yarn. Fibers emerge from carding in a fine web, which is gathered together into a loose, fine web called a sliver. After carding, fibers are taken through a number of stages to become yarn (Humpries, 2004).

#### *Combing*

An extra process is introduced called combing for high quality yarns. The purposes of combing are to 1) remove short fiber, and 2) improve fiber orientation (Lord, 2003).

#### *Drawing (Drafting) and Doubling*

This is the process of running slivers between sets of rollers, each moving faster than the ones before, which draw out or draft a number of slivers to the thickness of one: this process is repeated until the fibers are well mixed (Holz, Leinders and Hartung, 2004).

#### *Slubbing*

Slubbing draws the sliver out to a strand about the size of a pencil, called roving, which is given a very slight amount of twist. This is the last stage before actual spinning into yarn (Humpries, 2004).

#### *Spinning*

During spinning the roving is drawn-out to yarn size and given considerable high twist to become yarn. In ring spinning, twist is inserted as the fibers from the roving are carried by the traveler around the edge of the ring, inside which is the faster rotating spindle (Lakshimi et al, 2001).

### *Carded Yarn vs Combed Yarn*

Carded yarn has a fuzzy appearance and is loftier than combed fiber. Fabrics made from carded yarns have a more hairy surface and will pill more than fabrics of combed yarn. Only the “elite” of spun yarns are combed as well as carded. Combing removes any shorter fibers and arranges the remaining longest fibers more or less parallel to each other. During combing, about 15% further weight is lost (Humpries, 2004). Combed sliver has a ‘silky’ appearance (Lord, 2003).

#### **3.1.2 Open-End Spinning**

The basis of open-end spinning is that fibers are added to an “open end” of a yarn. Twist is applied to newly added fibers converting them into yarn, and the new elements of yarn are continuously removed from the twisting zone (Lord, 2003).

#### **3.1.3 Low- Twist Yarn**

The first basic difference between low-twist and the other cotton yarns is the fibers. While ring spun towels use a combination of long and short staple cotton fiber, low-twist must be constructed only from longer staple cotton yarn. After the fiber is made into “low-twist” yarn, it must be wound with Polyvinyl alcohol (PVA) yarn to keep the cotton intact without the need for twisting. The PVA dissolves during dyeing, leaving the extremely low-twist cotton behind (Lazaro, 2003).

This type of yarns is called low-twist, no-twist, or zero-twist –although it has a very low twist. MicroCotton®, to date the best-known of the branded low-twist labels, is a trademark registered to Sharadha Terry Products Ltd in India (Lazaro, 2003).

#### **3.1.4 HygroCotton®**

The spinning technology of HygroCotton®, which is a trademark of Welspun, gives each cotton strand a

hollow core that wicks moisture, thus makes the towel absorbent. If long staple cotton, like Egyptian or Pima, is used, a soft hand will be gained (Leizens, 2005).

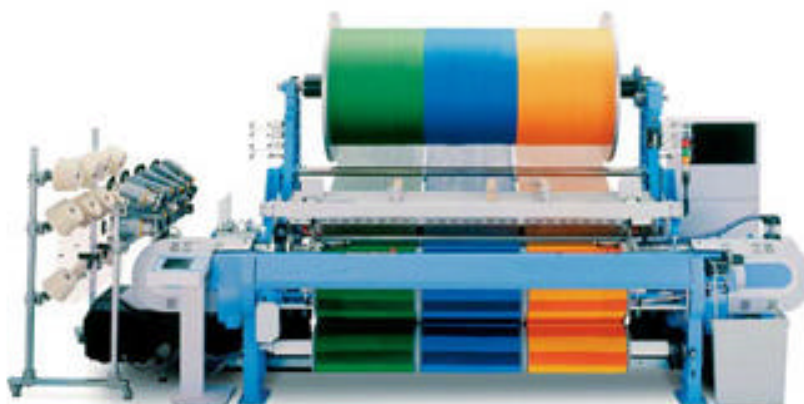
### 3.2 Terry Weaving

The production of terry fabrics is a complex process and is only possible on specially equipped weaving machines. See Figure 5. Three yarn systems are woven in the terry loom compared to the two system types of traditional weaving: Ground warp, pile warp and weft. The two warps are processed simultaneously: the ground warp, with tightly tensioned ends and the pile warp with lightly tensioned ends. A special weaving method enables loops to be handled with the lightly tensioned warp ends on the surface (Adanur, 2001). Ground warps and pile warps are unwound separately, warped onto two different section beams and sized separately. The processes they undergo show some

differences from each other. Weft or filling yarns are wound onto bobbins in required softness and lengths. In Figure 6, the flow chart of terry weaving process is shown (Acar, 2004).

In drafting or drawing in, ground and pile warps are passed through heddle eyes in the heald frames or harnesses, through ground and pile drop wires and through special terry reeds which have double teeth (Phillips, 2002).

Warps are fed into the loom from two beams: The ground and pile warp beams. The tension of the pile warp beam is lower than that of the ground warp beam; therefore the pile warp beam delivers higher length of warps than does the ground warp beam does. A special reed motion lets this extra length of pile warp form loops (Adanur, 2001). Terry weaving is described as “slack tension warp method” by Humpries (2004).



*Figure 5 Terry Weaving Machine G6300F (Smit Textile, 2005)*

#### 3.2.1 Preparation for Weaving

Increasing demands are being made on warp quality due to the ever increasing speed of looms and weaving machines. Weaving preparation consists of procedures which are carried out before weaving in order to obtain good quality fabric by ensuring warp and weft performance (Ajmeri and Ajmeri, 2003).

##### 3.2.1.1 Warping

Warp ends should be wound onto the section beam in accordance with the required weave, total number of ends, length and the required warp density (epi) of the fabric. By setting the yarn tension consistently during warping throughout the warp beam, the sizing may be applied in a more homogenous manner throughout the beam (Diehl, 2004).

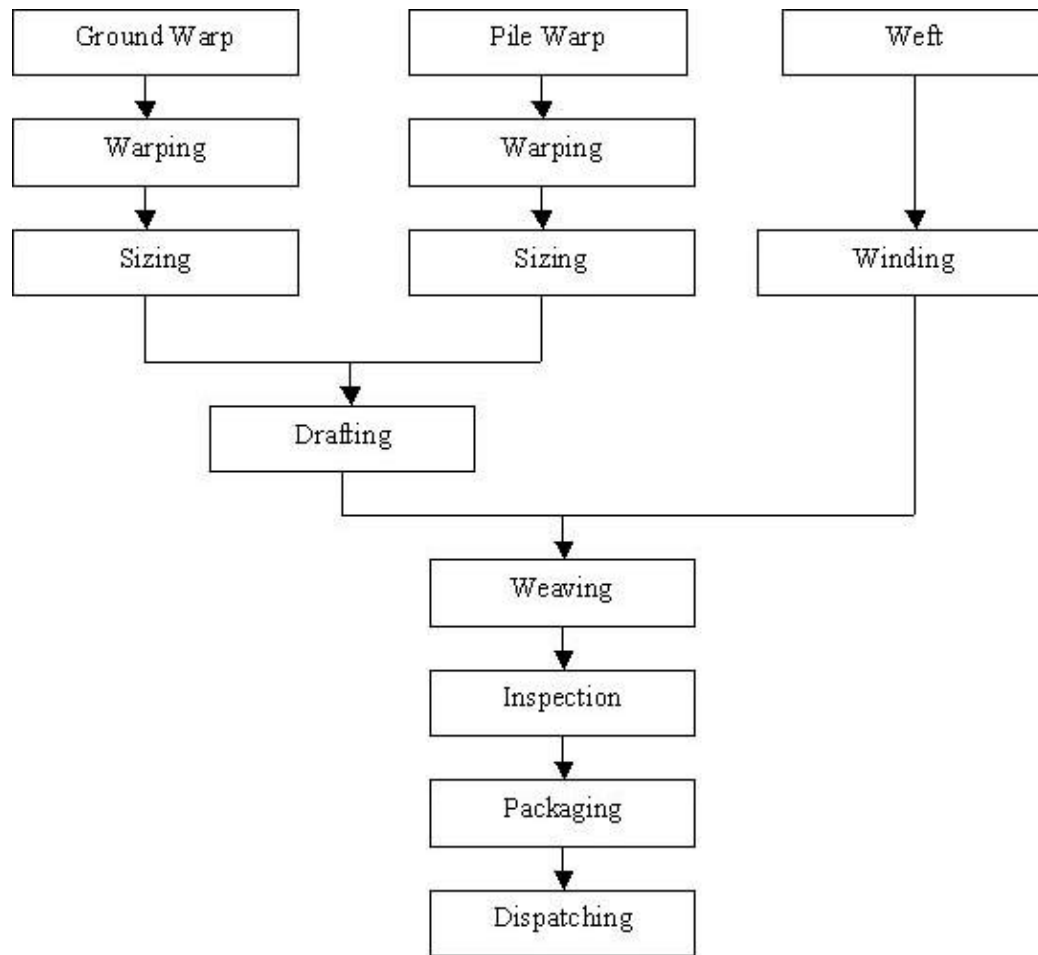


Figure 6 Terry Weaving Flow Chart (Acar, 2004)

The objective of the warping systems is to present a continuous length of yarn to the succeeding process with all the ends continuously present and with the integrity and elasticity of the yarn as wound; fully preserved (Khatwani et al, 2003). In this process, yarn ends from packages which are placed on the warping creel according to the specified warping plan are wound onto the beam after passing through guides, tension regulators and the accordion comb. Any yarn breakages are determined by tension sensors due to the decrease in warp tension and when a yarn break occurs, the machine stops automatically (Diehl, 2004b).

Two systems can be used for the warping process: Direct warping and sectional warping (Mohammed, 1999). If the creel capacity is sufficient and the number of total warp ends is not very high, the ends which are drawn from the creel can be wound directly onto the warp beam or section beam. This system is known as the direct warping system. If the fabric width is high or the warp density is so high that it necessitates a high number of warp ends or the warp has a color repeat, warping is carried out section by section. In this system which is known as sectional warping a definite number of warp ends are unwound from the creel and are wound on a cone shaped warping drum

forming a specified width. The process is repeated until the required end count is reached. In the second step the warp ends which are wound onto the cone drum are transferred to warp beam (Benninger et al, 2002). In direct warping the warp ends are wound onto a number of beams which will be joined in one weaver's beam after sizing, whereas in sectional drawing all the warp ends can be wound onto a single beam. Direct warping is much faster and thus cheaper than sectional warping as it includes only one step for the warp ends to be wound on to the warper's beams (Khatwani et al, 2003).

During warping, the zigzag comb moves upward and downward to the left and to the right as the warp flows in order to prevent warp ends mounting one over other. The warp ends which come through the zigzag comb are wound onto the warp beam with the help of a transferring drum. The pressure drum ensures the tightness of the sizing beam and consistent tension across width and length (Baser, 2004).

The running speed of the warper and the tension of the ends can be increased as the thickness of the yarn increases. The speed of the warper is also affected by the type, the strength, and the friction of the yarn. Also, the speed of the direct warper is higher than that of sectional warper (Ajmeri and Ajmeri, 2003).

Yarn packages for warp beams are placed on the warping creel, either V- or parallel creel (Mohammed, 1999). A parallel creel has the advantage of space saving on the plant floor and the V – creel has the advantage that the tension is kept constant throughout the beam width (Khatwani et al, 2002).

Packages are arranged on the creel according to the color pattern repeat. Each warp end is tied to the end which was left from the previous beaming work and is passed through the tension regulator. The packages should be in good condition, and all should have the same weight. Packages of different weight run out of yarn at different times: thus they would need to be

replaced at different times. This leads to loss of production time. Moreover the yarns left on the package after the work is done are transferred to another to either form a full package or to be sold off at discount prices as yarn waste. This leads to higher costs and loss of profit. Each one of the beams in a set which will be sized is required to contain the same length of warp ends (Acar, 2004).

Yarn breakages can occur due to thin places, nappy yarn, fly (the flying fibers from the yarns), bad package winding, or insufficient twist. If the creel is equipped with an air blower, the breakages which are due to fly will be prevented. The zigzag comb also should be equipped with an air blower (Benninger, 2005).

### 3.2.1.2 Sizing

Terry toweling is formed from cotton yarns, and as described earlier these yarns are produced by gathering cotton fibers together and twisting them. Some of the fibers in the yarn are totally in contact with other fibers, while some fibers are loose and protruding. Fibers of the latter type do not contribute to the strength of yarn totally and form a rough yarn surface (Rouette, 2001). Warp ends should be able to withstand great tension and friction forces during shedding and beat-up in the weaving process. As the number of end breakages increase so will the total cost and number of fabric defects increase (Dumitras et al, 2004).

Sizing is a pretreatment for yarns to be processed as warps for weaving into textile fabrics. Sizing protects the yarns against mechanical stresses in the weaving process by the application of a film of sizing agent which envelopes the yarn and which subsequently must be removed in finishing. The composition and quantity of the size application must be adapted to the type of yarn. Weaving efficiency is highly dependant on sizing. The type of sizing agent is also important in finishing which is why close cooperation between the weaver and the finisher is desirable. Sizing

is carried out in warp form from beam to beam (Rouette, 2001).

For the warp sizing process, the size has to be cooked in a kettle after which the size liquor is transferred to a heated storage vessel. The liquor is delivered from the vessel to one or several size boxes for application to the warp sheet. The sizing machine can have one size box or more than one size boxes to increase the effect of sizing (Benninger, 2005b).

The warp is squeezed between one or several pairs of rollers to remove excess size and to improve size penetration into the yarns. The impregnated warp then passes over drying cylinders supplied with heated steam. During this stage, water evaporates from the wet yarns and is normally collected under a hood and discharged by means of an extractor fan into the atmosphere through the roof (Rouette, 2001). A sizing machine is shown on Figure 7.

Sizing liquor consists of three main components, main sizing agents, auxiliary sizing substances and water.

### *Main Sizing Agents*

The sizing agents which are used today can be either natural sizing agents (starches, starch derivatives, cellulosic sizing agents) or manmade sizing agents (polyvinyl alcohol, acrylic) (Etc, 2005).

The most frequently used natural sizing agent is a starch derivative, carboximetil cellulose, which forms relatively more elastic but less strong size as compared to other sizing agents. The manmade sizing agent which has a widespread use is polyvinyl alcohol (PVA). The viscosity of the liquor can be adjusted during production. Film strength is high but its sticking ability is a little low. It dissolves in water. The desizing process should be carried out carefully; otherwise problems can occur in the wet processing. Another man made sizing agent is acrylic. It is usually used with other sizing agents to improve sticking ability and to prevent the size from settling (Etc, 2005).

Terry toweling is a heavy fabric and most of this weight comes from the pile warp. This situation increases size consumption and consequently increases sizing and desizing costs. An industrial application is to use starch or carboximetil starch in the ground warp, and carboximetil starch which can be removed in water for the pile warp. An industrial application is giving pile warp 3.5-4% size add-on and ground warp 13-14% (Rozelle, 1996).

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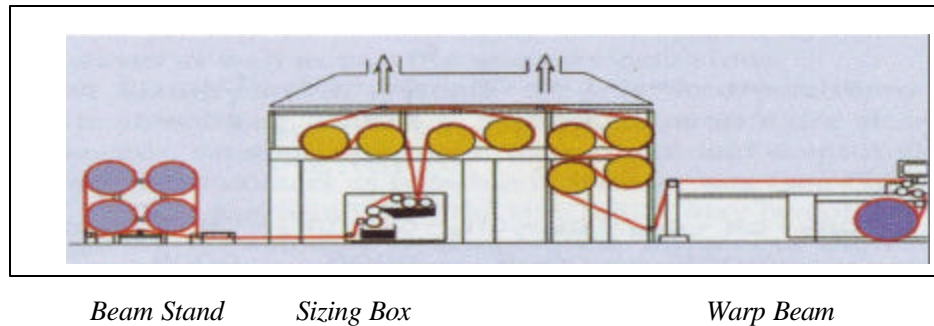


Figure 7 A Sizing Machine (Rouette, 2002)

#### Sizing Auxiliary Substances:

Sizing auxiliary substances are tensids, which help yarn absorb the liquor; softeners, which are used in order to soften the size film; lubricators, which are used to decrease the friction coefficient of sizing film, increase elasticity, improve moisture absorption; anti-static agents, which are used to prevent static electric; moisture holders, which are used for sizing film to ensure they hold 7-8.5 % moisture until the end of weaving; de-foaming agents and antiseptics (Acar, 2004).

In Appendix-3, an example of pile and ground warp sizing data comparison is given.

#### 3.2.1.3 Drafting for Terry Weaving

Drafting or drawing-in is the process of passing the warp ends through drop wires, heald or heddle eyes and reed dents in the designated order. With this step the warp ends are arranged in the required order, prevented from crossing over each other, and warp density is set. It is one of the most laborious of all textile processes, however, most weaving mills throughout the world continues to do this process by hand (Phillips, 2002).

In terry weaving two ends are drawn through each dent. The reed numbers which are most commonly used in terry

weaving are 110/2, 115/2, 120/2. Here the first number gives the number of the dents on the reed per 10 cm, and the second number gives the number of warp ends which pass through one dent (Acar, 2004).

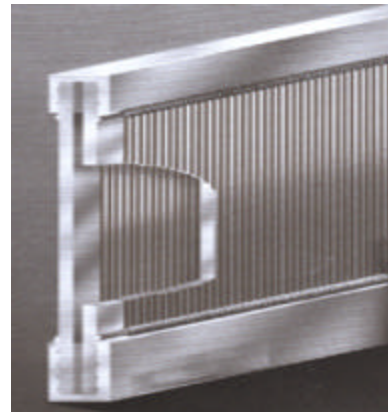


Figure 8 A terry reed (Sicos Reeds, 2005)

The reed which is used for terry weaving is different from that of normal weaving. The distinguishing characteristic of this reed is that its dents are arranged in two rows. This double row prevents entanglement of pile and ground warp ends, but this has a disadvantage. Any reed mark on the fabric becomes more obvious. However this makes it easy to distinguish the weave from the 3- or 4-pick terry fabric. In Figure 8, a reed which is used for terry weaving is shown (Sicos Reeds, 2005).

During weaving the flow of the warp ends should have as few obstacles as possible. Thus straight drafting is applied for pile warp ends (Acar, 2004). Straight drafting is achieved as the first end through first harness, second end through the second harness, to the final number of

harnesses. The order is sequential. If the warp density is high, skipping drafting can be used for both pile and ground ends. In skipping draft the drafting order does not follow the sequential order of ends (Baser, 2004).

In Figure 9:

P: Pile Warp ends,

G: Ground Warp Ends,

S: Warp ends of Selvedges

As seen from Figure 8;

Leno selvedge warp ends through heald frames or harnesses 1 and 2,

Pile warp ends through heald frames 3 and 4,

Ground warp ends through heald frames 5 to 12,

Leno selvedge warp ends again through heald frames 13 and 14,

Pile warp adds only use two heald frames whereas ground warp threads which have a very close number of ends use 8 heald frames.

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1	*																		
	S	S	P	P	G	G	P	P	G	G	P	P	G	G	P	P	G	G	S

Figure 9 Drafting in Terry Weaving (Acar, 2004)

### 3.2.2. Steps of Terry Weaving

In Figure 10, the components of an air-jet terry weaving machine are seen. The pile warp ends are let off from the pile warp beam (2), guided through the measuring unit (3), then join with ground warp ends which are let off from ground warp beam (1) and guided through the whip roll. Next, the two warp systems are

threaded through the drop wires, the headles, reed and with the control of cloth take up (6) are wound onto cloth roll after weaving(7). Positive controlled whip roll for ground warp (5) determines the length of ground warp to be let off, while terry motion (4) assures integration among pile and ground warp let off and cloth take up.

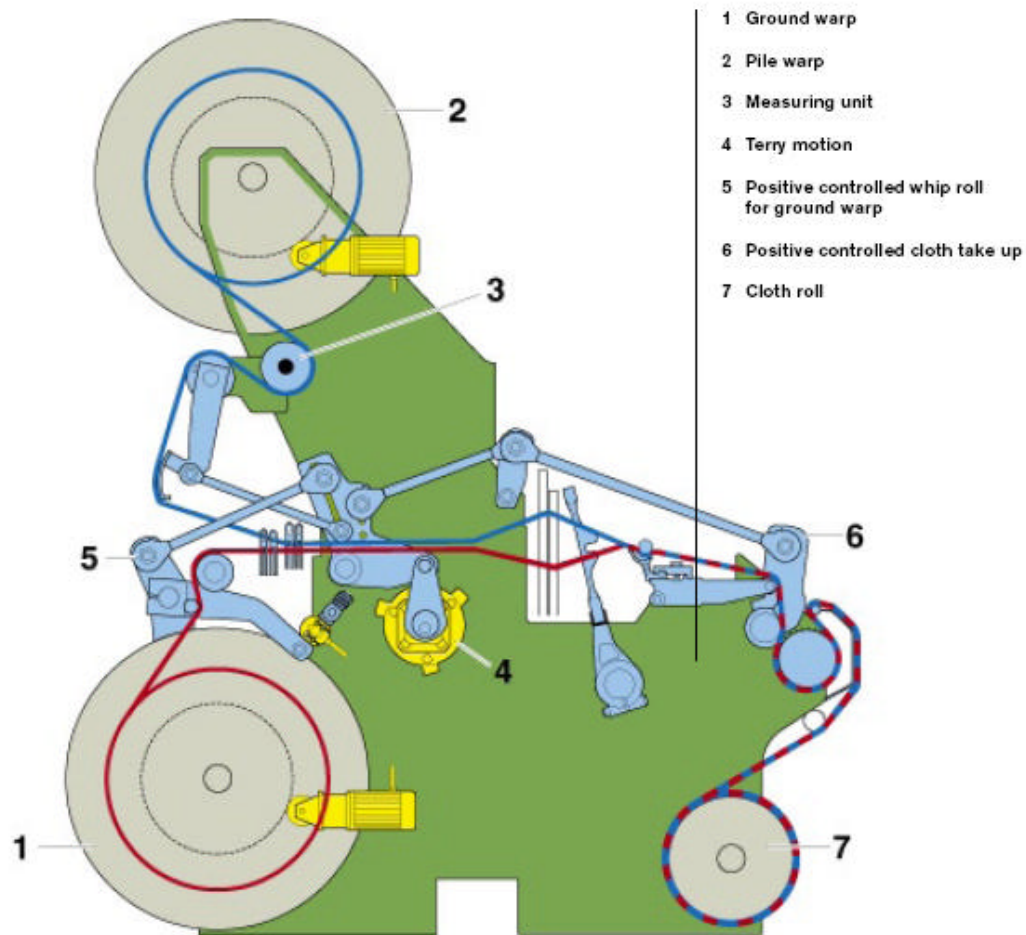


Figure 10 The components of air-jet terry weaving machine (Dornier, 2003)

### 3.2.2.1 Basic Movements

#### Shedding

Pile warp threads form loops and patterns through the shedding motion where as the ground warps form the ground with 1/1 plain weave, rib 2/1, rib 2/2, or rib 3/1 weaves. The rib 2/1 weave is the most frequently used weave for pile and ground warp systems separately. The shedding motion can be controlled in three ways for terry weaving as follows (Adanur, 2001).

#### Cam Shedding

The shedding motion is applied to the warp threads through heald frames or harnesses. The maximum number of

frames which is used in terry weaving machines is 10 (Dornier, 2003). This system can weave only very basic weaves. Weaving machines can reach very high speeds with an eccentric shedding system. To change the weave it is necessary to change the cam (Adanur, 2001).

#### Dobby Shedding System

The dobby shedding motion of the warp ends is created by the movement of the heald frames. The maximum practical number of harness frames in terry weaving machines with dobby is 20 (Dornier, 2003; Picanol, 2004). Dobby looms can produce weaves in limited numbers and limited designs. The difference of this system from the other traditional dobby looms is that the motion of the pile and ground

warps are transferred separately. There are also systems in which the pile warps are given shedding motion by dobby and the ground warp ends by cam (Baser, 2004).

#### *Jacquard Shedding System*

Each warp end is controlled through a separate motion. Very different and very complex structures can be woven. In terry fabric it is the pile warp which shows the design. The ground warp ends are woven 2/1 ribs (most commonly), 2/2 ribs, 1/1 plain weave and 3/3 ribs (the rarest) (Adanur, 2001). As these weaves do not require a jacquard shedding system, in some weaving machines, the pile warp ends take the shedding motion from the jacquard system whereas the ground warp ends take from the cam (Acar, 2004). Jacquard machines may either work in a traditional mechanical system with the help of needles and design cards or a contemporary electronic system which works through electronic transmitting elements with design files and electronic input (Humpries, 2003).

The pile warp ends are looser than ground pile ends, thus the shedding of the pile weft ends must be wider than that of ground warps. Otherwise, contact may

occur between the pile warp ends and the pick carrying device, which may cause high numbers of end breakages. A wider shed also improves the loop formation. Pile tension rod should guide the pile warp ends from the position which has the same level with the center of the shed. With this, the pile warp ends in the upper and in the lower shed will maintain the same tension. Thus, the pile loops on both sides of the fabric will have the same length (Acar, 2004).

#### **Filling Insertion**

##### *Filling Insertion with Rapiers*

Rapiers are popular in the production of terry cloth because of the flexibility they offer for production (Phillips, 2001). Rapiers are two hooks which carry the weft picks across the warp sheet. The first giver hook takes the weft pick from the yarn feeder and carries it to the center of the warp width. Meanwhile the taker hook moves from the other side of the weaving machine to the center. There, the two hooks meet and the weft pick is transferred to the taker hook. After that the giver hooks returns empty to the side it came from, and the taker hook carries the weft to the opposite side (Adanur, 2001).

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## Filling Insertion with Air Jet

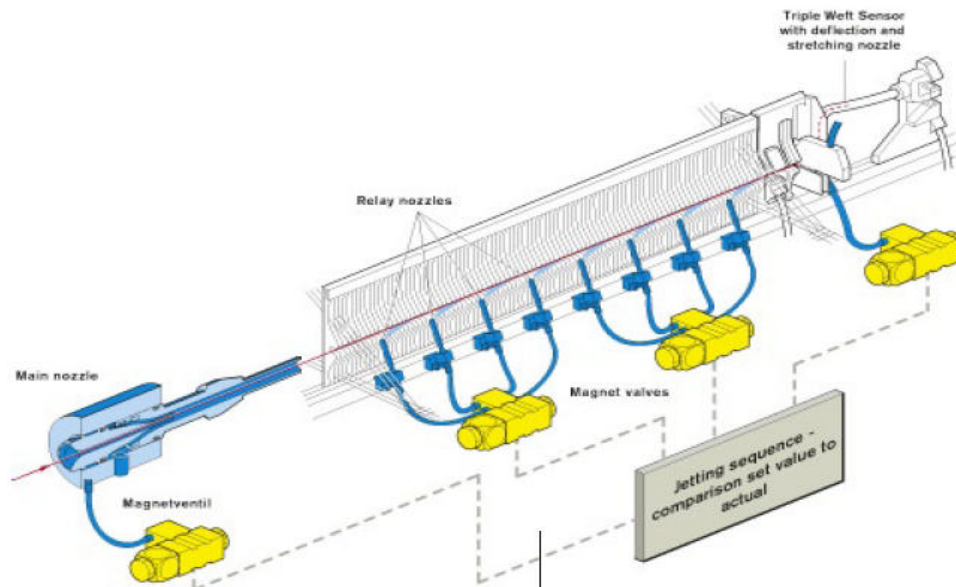


Figure 11 Air Jet filling insertion system (Dornier, 2003)

In air jet weaving a puff of compressed air carries the weft yarn across the warp sheet (Humphries, 2004). As seen in Figure 11, there are relay nozzles which are arranged in a definite order according to fabric width. These aid nozzles are connected to the main nozzles in groups. The air hoses which go to aid nozzles are also arranged in a row. The pick feeders also work with air and winds according to the fabric width. On the side where the pick arrives there are optical sensors which control the arrival of the filling picks. The maximum filling insertion rate practically achieved in terry weaving is 1800 m/min (Dornier, 2003).

### Filling Insertion with Projectile

A small gripper takes the cut weft yarn across the weaving loom (Humphries, 2004). This system is not very common in terry weaving as rapier and air jet filling insertion system are most commonly used ones (Promatech, 2003; Dornier, 2003;

Picanol, 2004; Smit Textile, 2005; Tsudakoma, 2005).

### Beat-up

The loops in terry fabrics are formed with a special reed motion and warp let-off system. These motions vary according to pick number per loop.

In 3-pick terry weaving, two picks are inserted at a variable distance –the loose pick distance- from the cloth fell. The loose pick distance is varied according to the desired loop height. When the third pick is beaten up, the reed pushes the pick group which includes the three picks, on the tightly tensioned ground warps, towards the fell and the loose pile warps are woven into the pick group are uprighted and form loops (Adanur, 2001). Depending on the weave, loops are thus formed on one or both sides of the fabric (Donaldson, 2003).

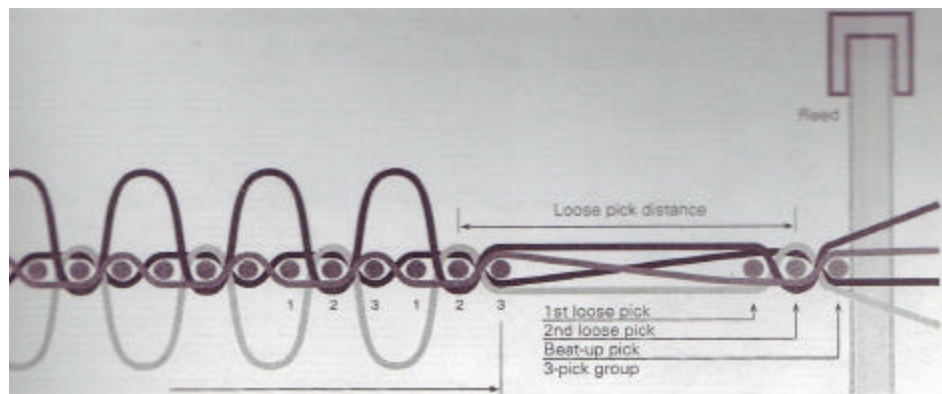


Figure 12 Loop Formation during Terry Weaving (Adanur, 2001)

In Figure 12, 3-pick terry fabric formation is seen. The first weft pick is the loop fixing pick, the second pick is binding pick, and the third one is the pile pick (Hearle, 1969) or the fast pick. The third pick is inserted into a completely reversed shed, as the pile and ground warp ends which are up, go down, and those which are down go upward, essentially locking the first in place. Thus, this motion prevents the drawing of the loop by the following sheds (Donaldson, 2003).

There are also systems in which the reed motion is constant but the cloth fell is moving, like Zax-e® Terry loom from Tsudakoma which has terry motion with a cloth fell shifting system or the ATVF ServoTerry® weaving machine from Dornier (Tsudakoma, 2005; Seyam, 2004). Here, a servo motor replaces the traditional terry cam for pile formation, so the reed does not drop back. When the reed is at the front center the fabric is positively driven toward the reed to form pile by the backrest and terry bar in combination with the temples (Seyam, 2004). The disadvantage of this system is that the friction which takes place during the forward-backward motion of the ends can lead to end breakage. Although weaving machines of different makes have different mechanism the main principle is the same (Adanur, 2001).

With today's machines, the maximum loose pick distance practically achieved is 24 mm, which gives some less than 12

mm loop height in G6300F® Terry Weaving Machine (Smit-Textile, 2005). It is possible to switch between 3-, 4-, 5-, 6- or 7- pick terry and 8 different pile heights in ServoTerry® (Dornier, 2003) and G6300F Terry Weaving Machines while the machine is running (Smit Textile, 2005). In Figure 13, a towel which is woven with different pile heights is seen.

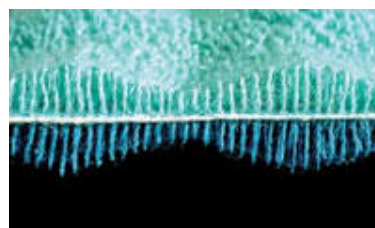


Figure 13 A Towel Woven with Different Pile Heights (Smit Textile, 2005)

### 3.2.2.2 Complementary Motions

#### Let-off

It was mentioned earlier that there are two warp systems including ground warp and pile warp, and thus two warp beams are let off simultaneously in a terry weaving machine. The ground warp ends move forward slowly and under high tension as the ground warp beam turns slowly. At the same time, the pile warp ends move forward quickly and loosely as the pile warp beam turns faster than the ground warp beam. Ground and pile warp beams are propelled by two different independent motors. Rpm's (revolution per minute) of the pile warp beams is



proportional to the required pile height. The higher speed delivers more yarn to increase the pile height. During let-off, pile tension is controlled continuously. This decreases yarn breakages, and avoids out-of-tolerance loop heights. In Figure 14, the Terry Motion Control System® of Tsudakoma is shown. Here, pile tension is determined by pile tension roll which is propelled by a motor guided by electronic pile tension control system (Tsudakoma, 2005).

The diameter of the pile beam is kept as large as the chassis of the machine

allows, so that it can hold the maximum length of pile warp. Keeping the pile beam's diameter large avoids changing the beam frequently during weaving. The width of the pile beam is between 76 - 144 inches (190 - 360 cm) and the diameter of its flange can be up to 50 inches (125 cm), while the flange diameter of the ground beam is up to 40 inches (100 cm). The Pile beam can hold more than 130 cu ft of yarn, with a gross weight exceeding that of many automobiles (Rozelle, 1996; Dornier, 2003; Smit Textile, 2005).

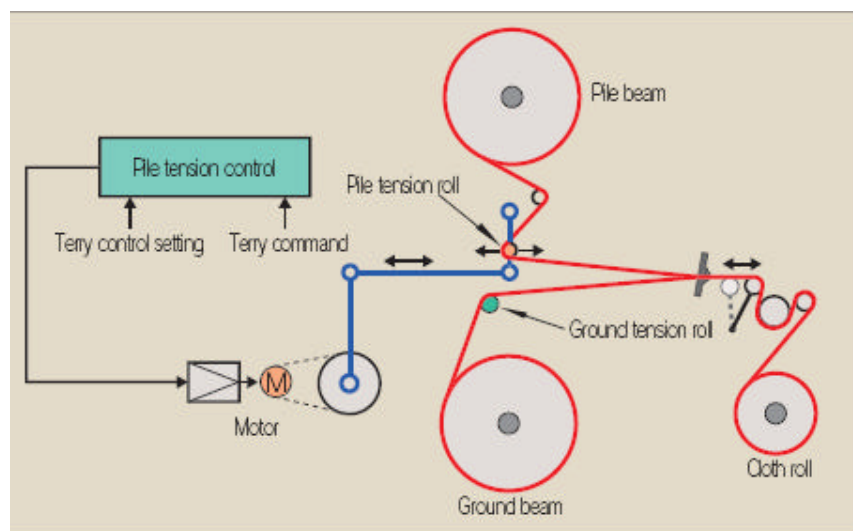


Figure 14 Pile Tension Control System (Tsudakoma, 2005)

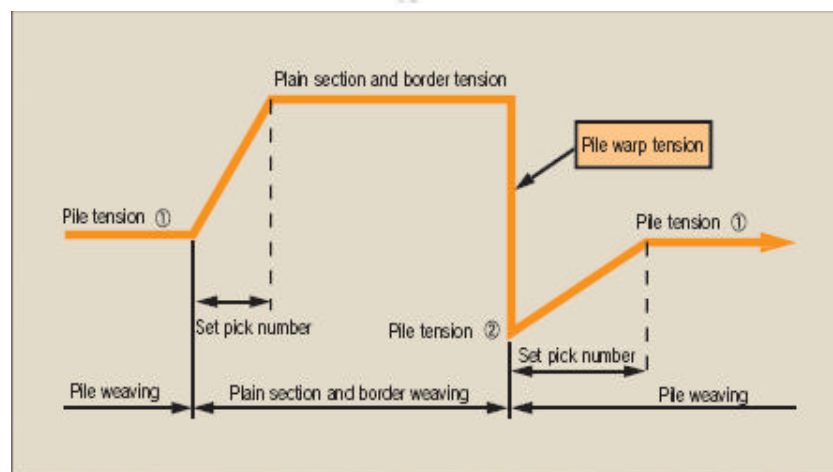


Figure 15 Diagram of Pile Warp Tension during weaving pile, plain and border parts (Tsudakoma, 2005)

The two warp systems are evenly let-off by a system of constant tension control from full to empty beam. This is controlled by a highly sensitive electronic device. The tensions of the pile and ground warps are detected by force sensors and electronically regulated (Adanur, 2001). Elimination of unwanted increase of tension of warp tension during weaving high density border and/or plain section is achieved by reducing let-off speed. In Figure 15, the diagram of pile warp tension in Zax-e® Terry looms from Tsudakoma during weaving of pile, plain and border areas is shown. In Figure 16, the diagram of loom rpm's in Zax-e® Terry looms of Tsudakoma during pile weaving and border weaving is shown (Tsudakoma, 2005).

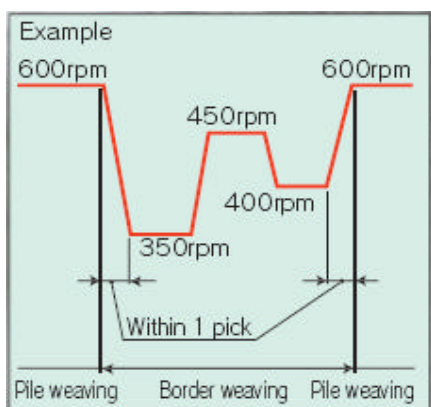


Figure 16 Diagram of Loom Rpm's during weaving pile and border areas (Tsudakoma, 2005)

To prevent starting marks or pulling back of the pile loops, the pile warp tension can be reduced during machine standstill. An automatic increase in tension can be programmed for weaving borders to achieve more compact weave construction in order to ensure a rigid border and/or to achieve nice visual effects via jacquard or dobby designs on the border (Sulzer Rurti, 1998).

The way the back rest roller system is controlled depends on the weave. During insertion of the loose picks and during border or plain weaving the warp tension between the open and closed shed is

compensated for by negative control. A warp tensioner with torsion bar is used for the ground warp, and a special tension compensating roll is used for the pile warp (Sulzer Ruti Inc, 1998).

## Take-up

The pick density is automatically controlled by synchronizing the take-up motor rotation with the loom speed. The take-up motor rotates the cloth pulling axle. The cloth pulling axle is covered with needles which pricks the terry fabric and assures that the thick fabric winds on the take-up roll evenly with a constant width (Acar, 2004). The electronically controlled cloth take-up guarantees exact weft densities in every terry towel and a faultless transition between pile and border (Smit Textile, 2005).

There are five elements of a take-up system. These are:

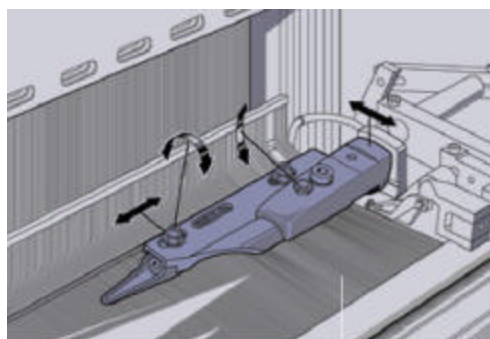


Figure 17 A Temple (Dornier, 2003)

### 1- Temple

The temple holds the width of the fabric as it is woven in front of the reed and assures the fabric to be firm at full width (Picanol, 2004). A temple is seen on Figure 17.

### 2- Length Temple

Length temple is located on the center of loom width between two side temples. There are grooves starting from the center and going to the left and right sides of the temple. It



ensures the terry fabric is open to the sides and remains straight and tense throughout the fabric width.

### 3- Cloth pulling Axle with Needles

It ensures the thick terry fabric keep its tension and width while being transferred from the length temple to the cloth transfer axle.

### 4- Cloth Transfer Axle

It increases the contact angle between the terry fabric and cloth pulling axle with needles and transfers the fabric to take-up roll.

### 5- Take-up Roll

The fabric which comes from the transfer axle is wound on take-up roll (Acar, 2004).

## 3.2.2.3 Auxiliary Motions

### Selvedge Forming

A length-wise edge of a woven fabric is called selvedge or selvage. The main purpose of the selvedge is to ensure that the edge of fabric will not tear when the cloth is undergoing the stresses and strains of the finishing process. This is achieved by making the selvedge area stronger than the body of the cloth using heavier and plied warp yarns, increasing warp yarns per inch, and applying different weaves (Price, Cohen, Johnson, 1999). Two types of selvedge are formed during terry weaving (Dornier, 2003; Picanol, 2004; Smit Textile, 2005).

#### 1-Leno Selvedge

A leno weave at the edges of the fabric locks in the warp yarns by twisting the last two warp yarns back and forth around each pick. They are made with special leno weaving harnesses (Adanur, 2001). Leno selvedges predominate in terry weaving (Dornier, 2003). In Figure 18, a leno selvedge forming system for terry weaving is shown. In Figure 20 (I), the diagram of a leno selvedge is shown.

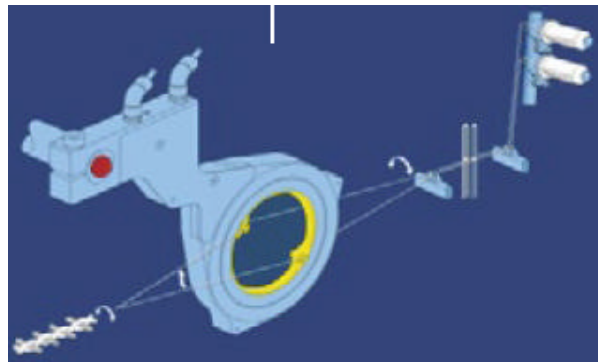


Figure 18 Leno Selvedge System Motoleno® (Dornier, 2003)

#### Tuck-in Selvedge

The fringed edges of the filling yarns are woven back into the body of the fabric using a special tuck-in device. As a result the filling density is doubled in the selvedge area (Adanur, 2001). In Figure

19, the ZTN™ needless tuck-in devices which are used in Zax-e™ terry looms from Tsudakoma is shown. In Figure 20 (II), the diagram of the tuck-in selvedge is shown.



Figure 19 ZTN needleless tuck-in device (Tsudakoma, 2005)

As the width of the towels is usually much narrower than that of the weaving machine width, more than one towel may be woven at the same time. Thus, selvages are formed not only at the sides but also several selvages should be formed on the sides of each towel panels woven together. For this reason special

selvage forming systems are produced for terry weaving. One example is Dornier's PneumaTuckers® for outside and center selvages, which are the selvages of individual towel panels when they are woven on a loom side by side (Vonwiller, 2001). Another example is shown in Figure 18.

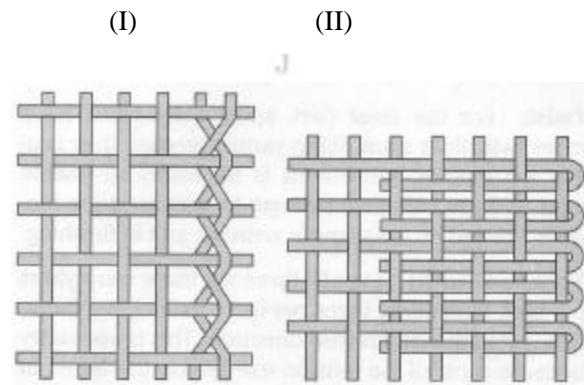


Figure 20 Selvages in Towels (Price, Cohen, Johnson, 1999)

(I) Leno Selvage

(II) Tuck-in Selvage

### Weft Color Choosing Motion

There are special color selection systems for inserting the required pick

color while weaving different filling colors. Terry weaving machines have weft color selection systems which allow maximum twelve different colors or type

of filling to be woven, including novelty yarns like chenille (Promatech, 2003; Dornier, 2003; Picanol, 2004; Smit Textile, 2005).

### **Pick Control**

The pick control mechanism or pick finder detects the weft breakage. At a filling break, the machine stops and moves at reverse slow motion – automatically – to free the broken pick. It has a significant role in reducing the down times for repairing filling breaks and thus the starting marks can be avoided (Picanol, 2004).

### **End Control**

Drop wires which are hung individually on each warp end, fall down when a warp end is broken or is very loose, closes down the electric circuit and thus shutting down the weaving machine (Baser, 2004).

### **Weft Measuring and Feeding Motion**

During terry weaving in shuttle-less looms, the weft is inserted from one side with the help of rapiers, or air jet nozzles. A predetermined length of weft yarn under the necessary tension should be inserted during each picking. Before each picking motion, a definite length of weft pick is measure, stored usually on drum accumulators and released for picking. The weft feeders carry out this function. They pull the weft picks from the yarn packages and wind them helically over a turning cylinder. Winding speed determines the weft length (Dornier, 2003).

### **3.2.3 Terry Designing**

Terry fabrics are often very complex with different colored warp ends in combination with loop patterns. They are subject to changing fashions, and the market is constantly demanding new qualities and designs. The rapid development of electronics has enabled fabric designers to produce completely

different patterns. Via a servo motor, the beat-up position for each pick, and, thus the type of terry and the pile height can be freely programmed from one pick group to another. In this way nearly 200 different loose pick distances, and hence the same number of pile heights, can be programmed in any order. For example, three- and four-pick terry and even fancy types of terry can be combined in the same fabric. This gives the fabric designer a broad range of patterning options and the weaving engineer the weaving structure for improving fabric performance, because transition from one pattern element to the next can be woven with greater precision (Adanur, 2001).

With these capabilities, a new patterning method, called sculptured terry, has been developed. At each full beat-up, two pile loops of different heights can be formed in the filling direction. The secret of this method of pattern formation lies in the fact that two loose pick groups formed at distances corresponding to the pile heights are beaten up to the cloth fell together (Sulzer Ruti, 1998).

For two short loops the pile yarns are woven into both loose pick groups and for one large loop into the second loose pick group only. The greatest challenge is to develop a basic weave which results in neat loops without excessive friction between warp and filling at full beat-up. The solution is found in a special seven pick weave combined with full beat-ups at the sixth and seventh pick. In this way, a second pile height is also formed in filling direction, making sculptured patterning possible by the difference in pile height in warp and filling direction (Adanur, 2001). In Figure 21, a terry towel pattern which is produced with this technique is shown. In Figure 22, the diagram of seven pick terry design is shown.

A requirement for this kind of pattern formation is a freely programmable sley traveling on a rapier weaving machine. Microprocessor control allows the loose pick distance to be programmed easily and

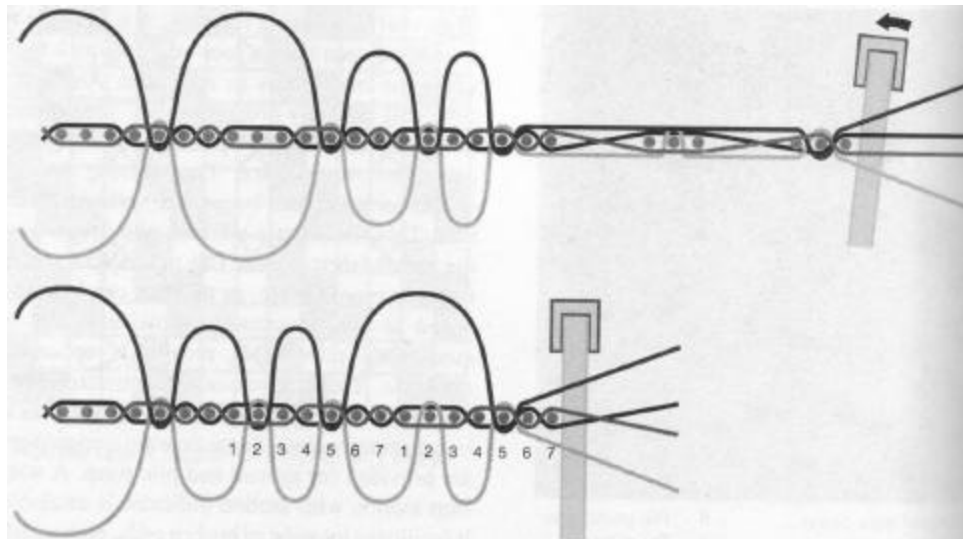
individually for each pick (Sulzer Ruti, 1998).

The loop formation system with full electronic control lets you alter the height of the loop by accompanying the

electronic weft ratio variator device on jacquard looms to program different weft ratios like 3-pick terry, 4-pick terry and so. By this method, different heights of loops can be achieved in the same shed (Promatech, 2003).



*Figure 21 A terry pattern achieved by weaving two different heights of loops (Smit Textile, 2005)*



*Figure 22 Special seven filling terry design with two-pick groups and full beat-up (Adanur, 2001)*

### 3.3 Shearing

It is quite common practice to shear the terry loops after manufacture in order to create a cut-pile effect. Many hand towels are sold with one face showing the traditional terry loop, whilst the other side shorn to give the velour effect (Donaldson, 2003).

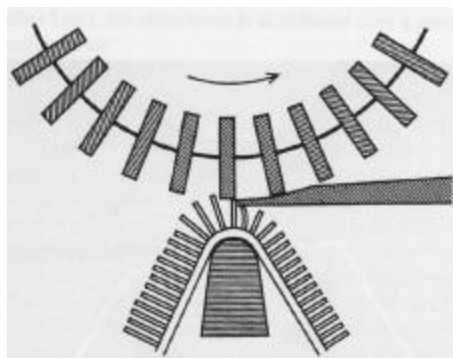


Figure 23 A Diagram of Shearing Process (Rouette, 2001)

Shearing is applied to the pile fabric, by passing it over a cylinder with blades like a giant cylindrical lawnmower. The velour fabric is then brushed with bristles set in a cylinder to remove cut bits of fiber. Brushing leaves the surface fiber lying in one direction so care must be taken to have all the fabrics in the same batch laid out in the same direction, or light will reflect off various pieces differently (Humpries, 2004).

In Figure 23, a simplified diagram of the shearing process is given. The pile fabric is guided across the shearing table and is sheared between the shearing blades mounted on a cylinder and a fixed blade (Rouette, 2001).

#### *Sculptured or carved design*

Sculptured design is different from the one which is achieved during weaving by using long and short loops. This involves considerably more processing after weaving. The pile fabric which has been woven with single pile loop height is first embossed, then the pile left upstanding is sheared off, and that which was flattened

is brushed up, leaving the sculptured or carved design (Humpries, 2004).

### 3.4 Dyeing and Finishing of Terry Towels

As discussed earlier the main fiber which is used in towels is cotton. As cotton fiber is not sensitive to alkali or chlorine bleach but is to acids, all the dyeing and finishing processes must be planned with these conditions (Humpries, 2004). Like other textile materials the dyeing and finishing stage of terry towels generally follow the workflow shown below:

- Pretreatment
- Coloration (Dyeing or Printing)
- Finishing (Ali, Ali and Speight, 2005).

#### 3.4.1 Pretreatment

Fibrous textile materials need a pretreatment before dyeing. Fiber preparation ordinarily involves scouring to remove foreign material and thus ensures even access to dye liquor from the dye bath. Cotton must be boiled and bleached to remove pectin and cotton seeds (Humpries, 2004). Sizing substances also must be eliminated. The steps of pretreatment are shown below:

- Desizing
- Scouring
- Bleaching

##### 3.4.1.1 Desizing

Desizing is intended to remove size from the fabric to ensure even bleaching, level dyeing and soft handle (Rouette, 2001).

Desizing processes differentiate according to the sizing agent used.

- I- Enzymatic Desizing: This classical desizing process consists of removing the starch from towel fabric using enzymes. This desizing process simply involves liquefying the film of size on the product.

Bacterial, malt and pancreas amylases are used as desizing agents (Rouette, 2001).

- II- Oxidative Desizing: The power of oxidizing agents to break down starches supports this method. However this method is relatively uncommon because damage to fiber can never be completely avoided during this method (Rouette, 2001).
- III- Desizing of Water-soluble Size using a Washing Procedure: Sizing films like polyacrylates, or polyvinyl alcohol are removed from the fabrics by this method (Rouette, 2001).

#### 3.4.1.2 Scouring

Scouring is the preparative process for bleaching and dyeing of fabric to remove the primary wall of cotton fiber (Rouette, 2001). The process is achieved near the boil in a kier with high-alkalinity built detergents (Humpries, 2004).

#### 3.4.1.3 Bleaching

This process is carried out safely with strong oxidizing agents. It removes the last of plant impurities called trash or motes which could not be removed by scouring (Humpries, 2004). The material is bleached by means of sodium hypochlorite, sodium chlorite and mainly hydrogen peroxide. A so-called “semi-bleach” is adequate for batches destined for dyeing or printing rather than to be offered to the customer as a white towel (Rouette, 2001).

#### 3.4.1.4 Optical Brightening

The process of adding optical brighteners to fabric can be considered a type of dyeing process. This process is used in towels which are going to be sold as white towels in the market. Optical brighteners are color substances which absorb light in the ultra-violet range and emit it again in the visible range. They therefore bring about an illusion on

textiles, in that they raise the level of whiteness of the goods (Rouette, 2001).

### 3.4.2 Coloration of Towels

Coloration of towels can be achieved in three ways as follow:

- Fabric Dyeing
- Printing
- Package Dyeing

#### 3.4.2.1 Fabric Dyeing

Fabric dyeing is the most common way of coloration of fabric as is cheaper and easier than yarn dyeing or printing.

The process of dye application involves the transfer of dye from a solution in a dye bath to the fiber. Additives such as wetting agents, salts and others are added to the dye bath along with the dye in order to facilitate the dyeing process (Ali, Ali and Speight, 2005).

The most commonly used dye type for terry towels is reactive dyes. The reasons for this are convenience for dyeing of cotton, high wet and light color fastnesses, and a rich color range (Humpries, 2004).

Dyes are applied to towels usually by batch rather than continuous methods. Batch dyeing is applied to towels using various machine types. The most used ones are pad-batch and overflow machines (Acar, 2004).

Overflow machines are the most commonly used machines for dyeing and finishing of terry towels. All the wet processes of the pretreatment, dyeing and finishing steps can be achieved in overflow dyeing machines (Acar, 2004). The towels are processed in rope form. The towel panels are loaded into the machine and both ends of towel panels are sewn together to form a very long band for continuous processing. As the machine runs, this band continually travels in a circle in the machine; sometimes into the liquor sometimes out of it (Rouette, 2001).

A pad-batch machine or padder, is an open-width dyeing and padding machine. The toweling is led by guide rollers into the dye liquor bath of the padder, impregnated and squeezed by rollers mounted above to guarantee a homogeneous dye take-up (Rouette, 2001). This machine is mainly used for velour towels, which can form creases in overflow dyeing machines (Acar, 2004).

Although scouring, bleaching and dyeing of cotton towels are commonly carried out in alkaline surrounding, there are also efforts to achieve these processes in enzymatic media. According to the results of the research of Jordanov and Mangovska, towels which are treated in enzymatic scouring, bleaching and dyeing gave better resistance to pilling, and better dimensional stability, better mechanical properties than those scoured by alkaline. (Jordanov, Mangovska; 2004).

#### 3.4.2.2 Printing

According to Rouette (2001), printing is local dyeing in zones according to patterns. Thickeners ensure that these zones defined by the engraved pattern are adhered to. The type and size of the artistic design determine the printing process and method of dye paste application. Various printing types like direct printing, discharge printing and resist printing and techniques like roller printing and full screen printing are available for the colorist to realize the print idea (Rouette, 2001).

#### 3.4.2.3 Package Dyeing

For package dyeing, yarn is wound on dye tubes as packages, each with a hollow center that allows liquid to flow through it. The packages are stacked on perforated, hollow posts, and dye liquor is pumped through these. Package machines are enclosed and can be pressurized so dye liquor can reach temperatures above atmospheric boiling point (100°C) for faster dyeing (Humpries, 2004).

The term yarn-dyed is associated with quality in woven fabrics. A pattern with dyed yarns looks sharper than one printed. The fabric will probably be more colorfast, and it is also reversible. The yarn dyeing process takes place between spinning and weaving steps (Humpries, 2004).

### 3.4.3 Final Finishing of Terry Towels

Final finishing includes all the finishing treatments applied to the fabric after dyeing and printing (Rouette, 2001). It can be divided into two:

- 1- Chemical (or Wet) Treatments
- 2-Mechanical (or Decorative),  
Treatments (Sivakumar, 2005)

#### 3.4.3.1 Chemical Treatments

Softening, hydrophilling and antimicrobial treatments are among the chemical finishing processes of terry towels.

##### *Hydrophilic Treatment*

Silicones are added to the towel to give hydrophilic properties. It is also used to give a soft handle (Teli, 2000).

##### *Softening*

The three basic types of softeners which are used on towels are cationic softeners, non-ionic softeners and silicones. Cationic softeners give good softness, but also some yellowness, so are only used for colored towels. Non-ionic softeners have less softening effect but are used in white towels due to the colorlessness of the chemicals. Silicones are the best and the most expensive of the softeners (Acar, 2004). Hydrophilic silicones also affect the hydrophility of the towel positively (Teli, 2000).

There are also applications of enzymatic softening using cellulases (Cox-TC, Genencor-International-Inc; 2001).



### *Antimicrobial Treatment*

Towels can be treated with antimicrobial finishes in order to prevent mold and mildew, reduce odor and minimize spread of harmful organisms (Cotton Inc, 2005b).

Two types of antibacterial and deodorant finishes are available. The first is applied during fiber-forming process, whereas the other is incorporated into the finishing process. The second approach is more versatile and widely adapted. Chemical entities are responsible for imparting antibacterial attributes including fungicides and bactericides (Sekar, 2001).

Obtaining antimicrobial properties by using antimicrobial fibers is achieved by anchoring the antimicrobial agent in the fiber. Trevira Bioactive (R) is an example of antimicrobial fiber used in towels which has proven to fully retain its antimicrobial effect after 100 domestic or 50 commercial wash cycles (Anonymous, 2004).

#### **3.4.3.2 Mechanical Treatments**

The main aims of dry treatments are to give the towels fuller volume, and dimensional stability and dryness (Acar, 2004).

#### *Tumble Drying*

The towel is given a fluffy and soft hand, and some particles are removed during drying. The common way is to use continuous tumbler dryer generally called Turbang®, which is the brand name of the machine brand. The second way is to use tumble dryers which are a huge version of domestic tumble dryers (Turbang, 2005).

#### *Stentering*

Stentering or tentering is a controlled straightening and stretching process of cloth which has been pulled out of shape due to the many vigorous finishing processes. The selvages of the cloth are attached to a series of pins/hooks/clips as

it is fed through a stenter machine which is an oven of controlled temperature. During the process, as the pins/hooks/clips are gradually placed further apart width ways, the cloth is slowly and permanently brought out to the desired width. Stentering gives the fabric particular dimensions of length and width, and eliminates creasing (Tekniktekstil, 2005).

### **3.5 Cutting and Sewing**

In this stage, towels pass through four steps.

- Longitudinal cutting
- Longitudinal hemming
- Cross cutting
- Cross hemming

These processes are achieved by scissors and standard sewing machines by workers or by machines specialized in towel cutting or sewing or even by automatic machines which can carry out some of or all of the mentioned processes (Acar, 2004).

Lengthwise cutting machines are used for the first step of this stage, longitudinal cutting of towels which have been produced on the weaving loom as several panels joined side by side. In these machines, there are several cutters which cut lengthwise between adjacent towel panels in order to separate them. The cutting process can be carried out by means of a pressing blade on a motorized roll in the lengthwise cutter (Akab, 2001). In Figure 24, a longitudinal cutting machine is shown.



*Figure 24 Longitudinal Cutting Machine 90/857(R) (Magetron, 2005)*



Next, longitudinal hemming is achieved by lengthwise hemming machines, most of which are usually equipped with two 401 chainstitch sewing machines, one on the right side and one on the left side, for the longitudinal hemming of towels. Labels can be attached during lengthwise hemming (Magetron, 2005). In Figure 25, a longitudinal hemming machine is shown.

After lengthwise hemming, towels pass through cross cutting as the third step. Transversal cutting machines carry out product stacking and automatic discharge. The cut product is stacked in layers one on the other (Magetron, 2005).

After cross cutting, cross hemming takes place. In both length and crosswise hemming, the hems are first folded, then sewn. In lengthwise hemming the border constitutes a problem due to its higher thickness. Problems are avoided by reducing sewing speeds in the border areas. Pile sewing is avoided by the pile raising device. Labels can be attached also in crosswise hemming (Sagar, 2005). In Figure 26, a cross hemming machine is shown.



Figure 25 Longitudinal Hemming Machine (Schmale Durate, 2004)



Figure 26 Cross Hemming Machine (Schmale Durate, 2004)

There are also hemming machines which use 301 lockstitch instead of 401 chainstitch. This reduces production rates because of the extra time needed to change the bobbin but assures more secure hems for high quality towels (Texpa, 2003).

Besides conventional hemming which consists of folding and sewing, towel edges can be secured by over-edge stitching. There are machines which are capable of stitching 4 sides of a towel with overedging like Auto-Runner(R) of Yamato (Yamato, 2005).

In automatic lines, both cross cutting and cross hemming processes are carried out on the same machine. In Figure 27, a cross cutting and cross hemming machine is shown.



Figure 27 Automatic Cross Cutting and Hemming Machine Mitho 2002(R) (Magetron, 2005)

#### 4. WHAT IS CONSIDERED A QUALITY TOWEL IN TODAY'S MARKET?

Market requirements for terry towels include performance, fashion style, color, pattern, and hand.

In addition to fashion statements, new yarn fabrications, new fibers and new weaving techniques are also a focal point in the world's towel market (Leizens, 2005). The big trends in towels all point to the surface interest whether from new yarn technologies, new fibers, jacquards or different varieties of terry, manufacturers and importers alike say surface interest is

becoming more important to retailers (SanFilippo, 2005).

Whether it is solid color, jacquard-woven or reactive print, bath towels are getting softer. A trend is seen to be moving toward a loftier, fuller towel with a soft hand and still maintaining all necessary quality specifications (Leizens, 2005).

The greatest growth in the towel market is expected to come from new yarn techniques and new fibers. MicroCotton® is an example of new technology in cotton spinning to differentiate and address the marketing of the bath towel, which suffered price erosion and is known by the type of yarn used in the construction (Leizens, 2004). As towel retailers are in search for unique, innovative and differentiated towel products, more and more towels are produced from fibers other than cotton like, modal, bamboo, seaweed, Lyocel and now soybean, corn (SanFilippo, 2005) and tri-blend bamboo, silk and cotton is also began to be used in towels (Corral, 2005). Micro-fiber towels are also crowding into the ultra-touch/high absorbency arena with a manmade synthetic product constructed primarily from a blend of polyester and nylon with polyamide (Lazaro, 2003).

With a super-soft, antibacterial, scented or anti-allergenic towel, the market has become somewhat like the apparel industry with new technology and new fibers being used to create a common interest (Corral, 2005). The spa category continues to be a lucrative bet for towel suppliers, which serves the market with more luxurious and expensive toweling like “The Hamam Experience”, the Turkish Bath Experience with the textured towels in neutral colors made from combed Turkish cotton (Leizens, 2005).

Two-ply yarns and jacquard constructions are on the rise for improved appearance, while embellished towels are plateauing. Retailers desire unique, innovative and differentiated products (SanFilippo, 2005).

Towel pricing is a function of several factors: among them, the size and weight of the towel, the grade of cotton fiber used and markup of each retailer (Leizens, 2004b).

Upland cotton is considered as the standard grade of cotton used for opening-price-point towels. After Upland comes California, then Pima, Supima, Egyptian and Low-twist. Each towel has a different hand, with the low-twist cotton being the softest (Leizens, 2004b).

Price is not the whole story for the market when purchasing terry towels. The U.S. terry towel imports have grown 275% between 1989 and 2003 (Cotton Inc, 2003b). The price of towels from India, the largest foreign supplier, has been generally below the world average price of towels destined for the U.S. In 2000, when prices of Indian towels imported into the U.S. surpassed the world average price, India lost market share the following year. In contrast, Turkey has been gradually expanding its share of towel shipments despite prices exceeding the world average by an average of 179% between years 1989-2002. From 89 to 02 Turkey climbed from 22<sup>nd</sup> to 5<sup>th</sup> among foreign suppliers of terry towels. Turkish bath towels are sold by catalog retailers at prices well above the US average due to their quality (Cotton Inc, 2003b).

## 5 CONCLUSION

Quality terry cloth has to do more than dry well: it must envelop and caress and be soft and gentle to the skin (Promatech, 2003).

As it is understood from the previous sections, the fiber content and construction of terry towels plus every step of the production provide terry towel with features that serves its end use performance.

If the total consumption figures of the terry towel which are given in Section 1 are considered, this traditional woven textile product competes well against

nonwoven, high-tech towels thanks to its familiar, natural feeling to the body.

When the trends in terry towel marketplace are reviewed in Section 4 it is seen that the terry towel market is a rapidly growing and innovative market with the new technologies of spinning, which is special for towel end use, new fibers -both natural and manmade-, new weaving features, new finishes such as antimicrobial finishes. All these innovations are aimed to increase the value gained from terry towels.

In generally, there is not a comprehensive literature review related to terry towels. The most condensed area in the literature is on the terry weaving technology. When it comes to the spinning, weaving preparation, and dyeing-finishing areas related to terry towels, there is limited published research. In these areas, commercial internet cites, and machine brochures had to be used. These areas need additional research studies.

In the management literatures, the new trends in terry towel markets are stated such as new spinning technologies, new fibers or fiber blends. However, in textile technology literature, the researches related to these innovations could not be found. More research also should be carried out on these issues.

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## GLOSSARY (Textile Institute, 2002)

Absorbency: the ability of a textile material to take in and retain a liquid such as water, within the fibers and within the pores (interstices) of the material

Antistatic agent: a substance applied to a substrate to prevent the accumulation of a static electric charge

Appliqué: a cut-out design or shape attached to the surface of a fabric for ornamentation and frequently of a different type and/or color of material

Beam: a cylinder provided with end bearings and at each end of which may be mounted suitable flanges

Beating-up: The third of basic motions involved in weaving, namely shedding, picking, and beating-up. It consists of forcing the pick of the weft yarn left in the warp set up to the fell of the cloth by the movement of the reed.

Bleaching: a process for improving the whiteness of textile material, with or without the removal of natural coloring matter and/or extraneous substances

Blowing room, blowroom: the section in a cotton spinning mill where the preparatory processes of opening, cleaning, and blending is carried out.

Bobbin: A cylindrical or slightly tapered former with or without flange or flanges, for holding slubbings, rovings or yarns.

Carding: The disentanglement, cleaning and intermixing of fibers to produce a continuous web or sliver suitable for subsequent processing. This is achieved by passing the fibers between relatively moving surfaces over covered with card clothing

Chenille yarn: a yarn consisting of a cut pile which may be one or more of a variety of fibers helically disposed around axial threads which secure it.

Color fastness: the property of resistance to a named agency, e.g., washing, light, rubbing, crocking.

Combing: the straightening and parallelizing of fibers and the removal of short fibers and impurities by using a comb assisted by brushes and rollers.

Count of reed; reed number; sett: the number of dents per unit width of reed.

Count of yarn; yarn count; yarn number; yarn linear density; grist: Methods of variously expressing the mass per unit length or length per unit mass of a yarn.

Crease: a fold in a fabric introduced unintentionally at some stage at processing

Crease resistance: resistance to, and/or recovery from, creasing or wrinkling of a textile material during use.

creel : a structure for holding supply packages in textile processing

dent: the unit of a reed comprising a reed wire and the space between adjacent wires.

Desizing: The removal of size from woven fabrics

Direct warping: The transference of yarn from a package creel directly onto a beam.

Dobby: A mechanism for controlling the movement of the heald shaft of a loom.

Drafting: The order in which threads are drawn through heald eyes before weaving

Drawing-in: The process of drawing the threads of a warp through the eyes of a heald and the dents of a reed.

Drawing-in plan; drafting plan: An indication of the order in which ends are controlled by specified heald shafts in one weave repeat.

Drop wire; dropper: One of a series of metal strips suspended on individual warp threads during warping or weaving. When the thread breaks, the drop wire falls, causing the machine to stop.

Dullness: the color quality, an increase in which is comparable to the effect of the addition of a small quantity of neutral grey colorant: it is opposite of brightness.

Durability: the ability of a textile to perform its required function until a limited state is reached.

Dyeing: The application and fixing of a dye to a substrate, normally with the intention of obtaining an even distribution through out the substrate

Embroidery: a decorative pattern superimposed on an existing fabric by machine stitching or hand needle work

Enzyme: a complex protein usually soluble in water, the catalytic action of which is very specific, with a given enzyme catalyzing one particular reaction

Fell: the line of termination of fabric in the loom formed by the last weft thread.

Fiber: textile raw material, generally characterized by flexibility, fineness and high ratio of length to thickness.

Filling: a synonym for weft yarns

Finishing: descriptive processes, physically or chemically, applied to a material in order to produce desired effect.

Harness: healds and heald shafts and/or jacquard cords used for forming a shed

Heald;heddle: a looped wire, or flat steel stripe with an eye in the center through which a warp yarn is threaded so that its movement may be controlled during weaving.

Heald frame: a rectangular frame, which is used to hold healds in position.

Heald shaft; gear: A heald frame complete with healds.

Hollow fibre: a tube-like manufactured fiber



Jacquard: a patterning device and mechanism used to select individual warp threads in weaving or warp knitting

Kier boil; boiling: the process of prolonged boiling of cotton or flax materials with alkaline liquors in a large steel container known as a kier, either at or above atmospheric pressure.

Lap: A sheet of fibers or fabric wrapped round a core. In cotton spinning, the sheet of fibers from openers and scutchers, sliver-lap machines, and ribbon-lap machines are wrapped on cores.

Leno edge: a set of threads interlacing with a gauze weave either at the edge or in the body of a fabric. When in the body of a fabric, a leno edge is often referred to as a center selvedge

Let-off motion: A mechanism controlling the rotation of the beam to release warp on a weaving, warp knitting or other fabric-forming machine.

Linen: 1. Descriptive of yarns spun entirely from flax fibers. 2. Descriptive of fabrics woven from linen yarns.

Loom: a term used for weaving machine.

Lyocell fiber: a manufactured fiber of cellulose obtained by extruding cellulose dissolved in an organic solvent.

Mature fiber: fiber where a high degree of wall thickening has taken place during cotton growth.

Maturity ratio: the ratio of the actual degree of wall thickening to a standard degree of thickening equal to 0.577 (ISO 4912)

Mechanical finish: a finish obtained by mechanical means, e.g., shearing, calendaring

Mercerization: the treatment of cellulosic textiles in yarn or fabric form with a concentrated solution of caustic alkali whereby the fibers are swollen, the moisture regain, strength, and dye affinity

of the materials are increased, and their handle is modified.

Metallic yarn: a yarn which has free metal as a component.

Microfiber: a fiber or filament of linear density below approximately 1 decitex

Micronaire value: a measurement of cotton fiber quality which is an indication of the fiber specific surface. Low values indicate fine and/or immature fibers; high values indicate coarse and/or mature fibers.

Mildew: a growth of certain species of minute fungi.

Modal fiber: a manufactured fiber of cellulose obtained by processes giving it high breaking strength and a high wet modulus.

Moisture content: the ratio of the mass of moisture in a material to the total moist mass.

Nep: a small knot of entangled fibers

Overflow-jet dyeing machine: a general term for soft-flow jet and partial immersion dyeing machines. Their action is characterized by the textile material in rope form being lifted briefly from the dye bath, by a small diameter winch or reel, into an overflow reservoir and then carried along a transportation tube by means of a relatively gentle flow of dye liquor.

Pick; shot: a single weft thread in a fabric as woven

Pick finding: the procedure for locating the position of the incomplete pick in the weave repeat during weaving

Pile: a surface effect on a fabric formed by tufts or loops of yarn that stand up from the body of the fabric.

Plain weave: The simplest of all weave interlacings in which the odd warp threads operate over one and under one weft thread throughout the fabric with the even

warp threads reversing this order to under one, over one, throughout.

Plied yarn: a yarn in which two or more single yarns are twisted together in one operation, e.g., two-ply yarn, three-ply yarn

Preparation (fabric): the treatment given to grey fabrics to remove natural colorants, impurities and contaminants prior to coloration and/or finishing treatments.

Printing: the production of a design or motif on a substrate by application of a colorant or other reagent usually in a paste or ink, in a predetermined pattern.

Rayon fiber: a manufactured fiber composed of regenerated cellulose.

Reactive dye: a dye that, under suitable conditions, is capable of reacting chemically with a substrate to form covalent dye-substrate linkage.

Reed; sley: 1. A device, consisting of several wires closely set between two slats or baulks, that may serve any or all of the following purposes: separating the warp threads; determining the spacing of the warp threads; guiding the shuttle or rapier; and beating up the weft. 2. to draw ends through the reed.

Reed mark: a warpway crack in a woven fabric caused by a damaged or defective reed.

Rib fabric: a fabric whose surface consists of warpway (weft rib) or weftway (warp rib) raised lines or ridges.

Roving: a name given, individually or collectively, to the relatively fine fibrous strands used in the later or final processes of preparation for spinning.

Screen printing: a design reproduction process, developed from stenciling, in which print paste is forced through the unblocked areas of a mesh, in contact with the substrate. The mesh may be a woven fabric or a metal screen.

Seam: The join between two or more plies of pieces of material.

Overlock seam: two or more superimposed plies of material, aligned along their edges, are joined together, edge trimmed and oversewn in one operation, with overedge stitches having two or more threads.

Selvedge : longitudinal edges of a fabric that are formed during weaving.

Shear: to cut a nap or pile to uniform length or height

Shedding: a primary motion in weaving; the separation of warp threads, according to pattern, to allow for weft insertion prior to beating up

Short-staple spinning: the use of cotton spinning machinery to produce staple yarns from cotton or any other type of fiber processing similar length and fineness characteristics.

Silk: the protein filaments forming the cocoons produced by silkworms.

Size: a gelatinous film forming substance, in solution or dispersion, applied normally to warps but sometimes to wefts, generally before weaving, to protect the yarns from abrasion in the healds and reeds and against each other; to strengthen them, by the addition of oils, fats, to lubricate them.

Slack end: a warp thread or part of a warp thread that has been woven into the fabric at a lower tension than the adjacent ends which are tensioned normally.

Slack selvedge: a selvedge that is slacker than the adjacent fabric owing to incorrect balance of fabric structure between the ground and the selvedge or owing to insufficient tension when selvedge ends are being warped or woven.

Sley: that oscillating part of a weaving machine, positioned between the healds and the fell of the cloth, which carries the reed.

Sliver: An assemblage of fibers in continuous form without twist.

Slub: An abnormally thick place in a yarn.

Spin: to make a yarn or filament

Splitting: the separation of several warp sheets in the slasher-sizing machine

Staple length: the characteristic fiber length of a sample of staple fibers.

Stenter; tenter; frame: an open-width fabric finishing machine in which the selvages of a textile fabric are held by a pair of endless traveling chains maintaining tension

Take-up motion: a mechanism for controlling the winding-forward of fabric during weaving.

Temple: a device used in weaving to hold the fabric at the fell as near as possible to the width of the warp in the reed.

Temple marking: disturbance of the fabric surface as it passes through the temple during weaving

Terry: uncut loops in fabric. The term has widely synonymously with woven Turkish toweling

Terry fabric: a warp-pile fabric in which loops are created without positive assistance, by varying relative tensions of the fell and the reed. A high tension is applied to the ground warp and a very low tension to the pile warp.

Tight end: a warp thread or part of a warp thread that is tighter than the adjacent ends which are tensioned normally.

Tight selvedge: a selvedge that is tighter than the adjacent fabric owing to incorrect balance of fabric structure between the ground and the selvedge or owing to insufficient tension when selvedge ends are being warped or woven.

Upland cotton: a type of cotton which forms the bulk of the world's cotton crop.

It varies in average staple length from about 22 mm to about 32 mm.

Velour: a terry fabric that has had the tops of the loops cut off in a process subsequent to weaving. It is also known as 'cropped terry pile' and 'sheared terry pile'.

Warp: threads lengthways in a fabric as it is woven.

Warper's beam: a beam on which the yarn is wound on a warping machine.

Warping creel: a creel for holding yarn packages, usually in tiers and from which an assembly of ends can be withdrawn for warp-making.

Weave; structure: the pattern of interlacing of warp and weft in a woven fabric

Weave repeat: smallest number of ends and picks on which a weave interlacing pattern can be represented.

Weaver's beam: a roller on each side of which large flanges are usually fixed so that a warp may be wound on it in readiness for weaving.

Weft; filling; threads widthways in a fabric as woven.

J  
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## Appendix - 1

Terry towels can have piles on one or both faces. Terry weaves which have pile on one face are shown on Figure 1a, and those of toweling which have pile on both faces are shown on Figure 1b:

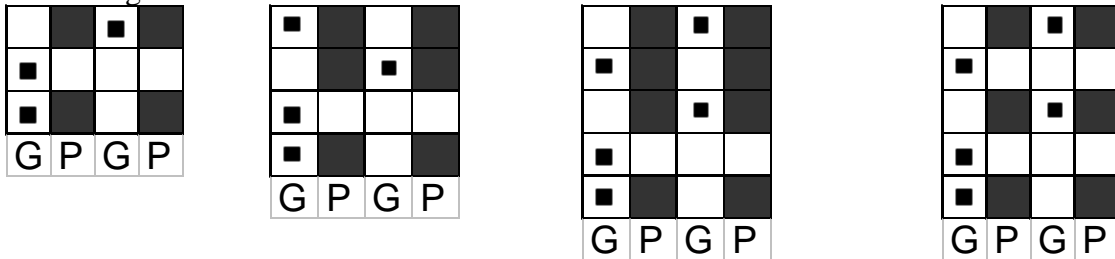
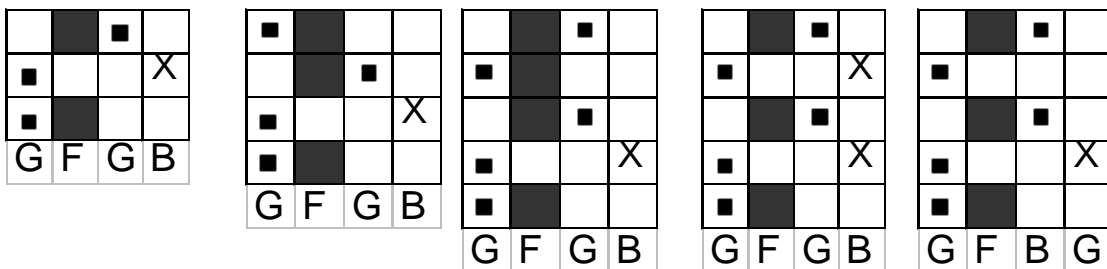


Figure 1a- Terry weaves with pile on only one face.

G: Ground Warp,

P: Pile warp.

Line #A Warp Order 1:1



Line #B Warp Order 2:2

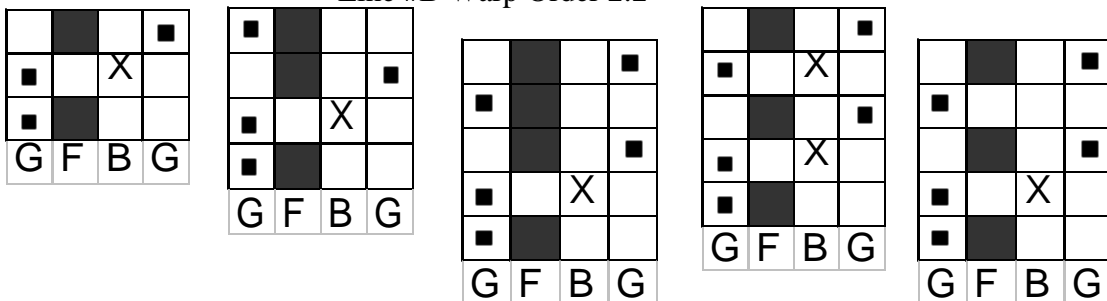


Figure 1b. Terry weaves with pile on both faces.

G: Ground Warp,

F: Front side Pile Warp,

B: Back Side Pile Warp (Baser, 2004).

## Appendix - 2

Woven Terry Fabric Specification Requirements (ASTM 5433, 2000).

Tested Criteria	Kitchen Towels	Dishcloths	Bath, Hand, Washcloths, Bath sheets
Breaking Force Length Width	178 N min 133 N min	220 N min 178 N min	178 N min 133 N min
Non-fibrous material	3% max	5% max	3% max
Dimensional Change: Length Width	10% max 5% max	10% max 5% max	10% max 5% max
Bow and Skew	6% max	6% max	6% max
Colorfastness: Laundering: Shade change Staining Crocking: Dry Wet Light (20 AATCC FU)	Class 4B min Class 3C min  Class 4D min Class 3D min Step 4B min	Class 4B min Class 3C min  Class 4D min Class 3D min Step 4B min	Class 4B min Class 3C min  Class 4D min Class 3D min Step 4B min
Absorbency	Pass	Pass	Pass
Flammability	Class 1	Class 1	Class 1
Laundered Appearance	Acceptable	Acceptable	Acceptable

### Appendix - 3

*Table 1 24/2 Ne 100% Cotton Combed Ground Warp and 20/1 Ne 100% Cotton Combed Pile Warp Sizing Data Comparison of a Towel Woven in Denizli, Turkiye (Acar, 2004).*

<b>Data</b>	<b>Ground</b>	<b>Pile</b>
Total number of pile warp ends	2196	2132
Sizing recipe	11 kg CMS+500 gr Glissofil Extra	18 kg CMS+500 gr Glissofil Extra
Volume of sizing liquor (lt)	500	500
Temperature of Cooking Tank (°C)	92	92
Temperature of Relaxation Tank (°C)	85	85
Squeezing Pressure Force (KN)	17	13,5
Average running speed (m/min.)	70	110
Immersion Tension Force in sizing Bath (N)	350	200
Wet tension force at the exit of sizing bath (N)	700	600
Dry tension force at the splitting area (N)	1000	800
Tension Force of winding of the beam (N)	1750	1250
Pressure Force on winding of the beam (N)	1750	1250
Tension force of warp braking (N)	900	800
Temperature of sizing bath (°C)	85	85
Refractometer (%)	3	4
Wet size intake ratio (%)	83	68
Dry size intake ratio (%)	2,5	2,7
Moisture ration of warp at the exit (%)	8	8
Temperature of Dryer cylinders (°C)	135	90