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Dedication

This work is dedicated to the faculty members of Fabric Manufacturing Department of National Textile University.
First and foremost, I would like to thank Allah who gave us strength, knowledge and capability to complete this piece of work. Two years ago we had this discussion in our team about lack of any compiled data based on calculation. We would jump to supporting in writing a book covering all the aspects in the target field. I would like to express my sincere gratitude to my colleagues, who saw me through this book; to all those who provided support, talked things over, read, wrote, offered comments, and assisted in the editing, proofreading and design. Their determined efforts have turned this book into a reality.

I would like to thank the Higher Education Commission, Pakistan for providing us the opportunity to publish this book.
The textile fabrics have a wide range of application in areas like apparels, home textiles and technical textiles. The manufacture of a cost effective quality product requires the careful planning and thorough knowledge of the production process. This objective cannot be achieved without the know-how of the calculations involved in the fabric formation process. The latest developments and automation in the textile machinery has resulted in a more efficient production cycle. Unfortunately, the published work available on the topic of woven fabric calculations is quite out dated, while no significant work has been reported on the calculations of knitted fabrics.

This book is organised into nine different chapters. Chapter 1 focuses on the systems for linear density of yarn, and their inter-conversion. Chapter 2 addresses the winding calculations. Chapter 3 and 4 are dedicated to warping and sizing calculations respectively. Chapter 5 is cloth calculations, while chapter 6 is weaving shed calculations. Chapter 7 highlights different theories and structural parameter of fabric geometry, while chapter 8 includes specialty calculations like terry towel, ball warping, filament warping and sample warping. The chapter 9 is dedicated to the knitting calculations, both warp and weft knitting.

The whole range of steps and calculations involved in the fabric formation process from amount of raw material to the costing of final product have been included in the book. I hope, this book is equally beneficial for the beginners, textile engineering students and professionals of the field.

Dr. Yasir Nawab
National Textile University
CHAPTER – 1

YARN COUNT CALCULATIONS

Muhammad Umair, Yasir Nawab

1. **Yarn count**

Yarn count is a system of expressing the fineness of yarn in terms of thickness. It is the relationship between the weight and length of yarn made. Different types of count systems formed for different types of yarn materials. Broadly the yarn count system is divided into two major categories:

- Indirect count system
- Direct count system

1.1 **Indirect count system**

In this system the count of yarn expresses the number of length units in one weight unit. This system is generally used for cotton, worsted, woollen, linen (wet spun), etc. It may be noted that finer or less bulky the yarn, higher is its count number or in other words, the size or bulkiness of the yarn is inversely proportional to the count number and that is why the system is known as indirect system.

\[
\text{Indirect Count} = \frac{\text{Length in appropriate unit}}{\text{Weight in appropriate unit}}
\]

Keeping in view the yarn material, different types of indirect count systems were developed like:

- **Cotton Count** \( N_{ec} = 8.33 \times \frac{L(\text{yards})}{W(\text{grains})} \)

- **Worsted Count** \( N_{ews} = 12.5 \times \frac{L(\text{yards})}{W(\text{grains})} \)

- **Woollen Count** \( N_{ewt} = 27.34 \times \frac{L(\text{yards})}{W(\text{grains})} \)

- **Decimal Count** \( N_{edc} = 7 \times \frac{L(\text{yards})}{W(\text{grains})} \)
\[ \text{Metric Count, } NM = \frac{L(Kms)}{W(Kgs)} = \frac{L(Mtrs)}{W(Grms)} \]

\[ \text{French Count, } N_{\text{efr}} = \frac{1}{2} \times \frac{L(Mtrs)}{W(Grms)} \]

1.2 Direct Count System

In this system the count of yarn expresses the number of weight units in one length unit. This system is generally used for silk, artificial silk, jute, etc. The size or bulkiness of the yarn is directly proportional to the count number. A coarser yarn will have a higher count number while finer yarn will have a lower count number. The system is used for very finer or very coarse yarns.

\[ \text{Direct Count} = \frac{\text{Weight in appropriate unit}}{\text{Length in appropriate unit}} \]

Keeping in view the yarn material, different types of direct count systems were developed like:

\[ \text{Tex Count} = 1000 \times \frac{W(Grms)}{L(Mtrs)} \]

\[ \text{Denier count} = 9000 \times \frac{W(Grms)}{L(Mtrs)} \]

\[ \text{DeciTex or Grex count} = 10000 \times \frac{W(Grms)}{L(Mtrs)} \]

\[ \text{Dram count} = \frac{\text{Weigh (Dram)}}{L(\text{hanks})} = \frac{1000}{27.34} \times \frac{W(Grains)}{L(Yards)} \]

<table>
<thead>
<tr>
<th>Sr #</th>
<th>Name of System</th>
<th>Unit of weight</th>
<th>Unit of Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>English cotton</td>
<td>1 lb.</td>
<td>Hank of 840 yards</td>
</tr>
<tr>
<td>2</td>
<td>French cotton</td>
<td>½ kg.</td>
<td>Hank of 1000 meters</td>
</tr>
<tr>
<td>3</td>
<td>Bump cotton</td>
<td>1 oz.</td>
<td>1 yard</td>
</tr>
<tr>
<td>4</td>
<td>Decimal (for all yarns)</td>
<td>1 lb</td>
<td>Hank of 1000 yards</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th></th>
<th>Metric</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Metric</td>
<td>1 kg.</td>
<td>Hank of 1000 meters</td>
</tr>
<tr>
<td>6</td>
<td>Worsted</td>
<td>1 lb.</td>
<td>Hank of 560 yards</td>
</tr>
<tr>
<td>7</td>
<td>Woollen (Yorkshire Skein)</td>
<td>6 lbs.</td>
<td>Skein or Hank of 1536 yards</td>
</tr>
<tr>
<td></td>
<td>Woollen (American Cut)</td>
<td>1 lb.</td>
<td>Cut of 300 yards</td>
</tr>
<tr>
<td></td>
<td>Woollen (American Run)</td>
<td>1 oz.</td>
<td>Run of 100 yards</td>
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<tr>
<td></td>
<td>Woollen (West of England)</td>
<td>1 lb.</td>
<td>Snap of 320 yards</td>
</tr>
<tr>
<td>8</td>
<td>Linen (wet spun)</td>
<td>1 lb.</td>
<td>Lea of 300 yards</td>
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<tr>
<td>9</td>
<td>Spun Silk</td>
<td>1 lb.</td>
<td>Hank of 840 yards</td>
</tr>
<tr>
<td>10</td>
<td>Jute, Hemp and Flax</td>
<td>1 lb.</td>
<td>Hank of 14,400 yards</td>
</tr>
<tr>
<td>11</td>
<td>Tex</td>
<td>1 gram</td>
<td>Hank of 1000 meters</td>
</tr>
<tr>
<td>12</td>
<td>Denier</td>
<td>1 gram</td>
<td>Hank of 9000 meters</td>
</tr>
<tr>
<td>13</td>
<td>Deci-Tex/Grex</td>
<td>1 gram</td>
<td>Hank of 10,000 meters</td>
</tr>
<tr>
<td>14</td>
<td>Dram</td>
<td>1 dram = 27.34 grains</td>
<td>Hank of 1000 yards</td>
</tr>
<tr>
<td>15</td>
<td>Fiber glass</td>
<td>1 lb.</td>
<td>Hank of 100 yards</td>
</tr>
</tbody>
</table>

1 pound ($lb$) = 16 ounces = 7000 grains = 453.6 grams

1 ounce ($oz$) = 28.35 grams

1 kilogram ($kg$) = 2.2046 lbs

1 meter ($m$) = 1.0936 yards (yds)

1 dram = 27.34 grain

**Different count systems are given below**
**Cotton Count**

\[
\text{Cotton Count} = \frac{\text{Length in hanks}}{\text{Weight in lbs}}
\]

Spun silk or spun rayon staple fiber system is same as English cotton count system:

**Metric Count**

\[
\text{Metric Count} = \frac{\text{Length in kilometers}}{\text{Weight in kilograms}}
\]

**Metric Count**

\[
\text{Metric Count} = \frac{\text{Length in meters}}{\text{Weight in grams}}
\]

**Linen or Hemp system**

\[
\text{Linen or Hemp system} = \frac{\text{Length in leas}}{\text{Weight in lbs}}
\]

**Worsted system**

\[
\text{Worsted system} = \frac{\text{Length in hanks}}{\text{Weight in lbs}}
\]

**Worsted system**

\[
\text{Worsted system} = \frac{7000 \times \text{Length in yards}}{560 \times \text{Weight in grains}}
\]

**American Cut system for Woollen yarns**

\[
\text{American Cut system for Woollen yarns} = \frac{\text{Length in cuts}}{\text{Weight in lbs}}
\]

**American Cut system for Woollen yarns**

\[
\text{American Cut system for Woollen yarns} = \frac{\text{Length in yards/300}}{\text{Weight in lbs}}
\]

**Yorkshire Cut system for Woollen yarns**

\[
\text{Yorkshire Cut system for Woollen yarns} = \frac{\text{Length in skeins}}{\text{Weight in lbs/6}}
\]

**Yorkshire Cut system for Woollen yarns**

\[
\text{Yorkshire Cut system for Woollen yarns} = \frac{7000 \times \text{Length in yards}}{256 \times \text{Weight in grains}}
\]

**Jute, Flax and Hemp count**

\[
\text{Jute, Flax and Hemp count} = \frac{\text{Weight in lbs}}{\text{Length in spyneldes}}
\]

**Jute, Flax and Hemp count**

\[
\text{Jute, Flax and Hemp count} = \frac{72 \times \text{Weight in grains}}{35 \times \text{Length in yards}}
\]

**Example 1.1:**

*If 1 bundle contains 200 hanks of cotton yarn, what is the count of yarn? (1 bundle = 10 lbs.)*

**Solution:**
We know that,

\[
\text{Cotton Count} = \frac{\text{Length in hanks}}{\text{Weight in lbs}}
\]

\[
\text{Cotton Count} = \frac{200}{10}
\]

\[
\text{Cotton Count} = 20 \text{ s}
\]

**Example 1.2:**

*How many hanks are there in 7 bundles of 60’s cotton yarn?*

**Solution:**

We know that, 5 bundles = 7 × 10 = 70 lbs

\[
\text{Cotton Count} = \frac{\text{Length in hanks}}{\text{Weight in lbs}}
\]

\[
\text{Cotton Count} \times \text{Weight in lbs} = \text{Length in hanks}
\]

\[
\text{Length in hanks} = \text{Cotton Count} \times \text{Weight in lbs}
\]

\[
\text{Length in hanks} = 60 \times 70
\]

\[
\text{Length in hanks} = 4200
\]

**Example 1.3:**

*If 120 kilometers of yarn weigh 3.5 kilogrammes, what will be the count in metric system?*

**Solution:**

In metric system, we know that
\[ \text{Metric Count} = \frac{\text{Length in kilometers}}{\text{Weight in kilogrammes}} \]

\[ \text{Metric Count} = \frac{120}{3.5} \]

\[ \text{Metric Count} = 34's \]

### 1.3 Count conversions

In many cases of yarn count conversions, we need to convert one type of direct or indirect count system to another type of direct or indirect count system to get equivalent count. If,

- \( L_1 = \) Length in known system,
- \( L_2 = \) Length in required system
- \( W_1 = \) Weight in known system,
- \( W_2 = \) Weight in required system
- \( C_1 = \) Count in known system,
- \( C_2 = \) Count in required system

We can convert to any required system by using the concerned formula as given below:

1. **Indirect to Indirect**:
   \[ C_2 = C_1 \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

2. **Direct to Indirect**:
   \[ C_2 = \frac{1}{C_1} \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

3. **Direct to Direct**:
   \[ C_2 = C_1 \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right) \]

4. **Indirect to Direct**:
   \[ C_2 = \frac{1}{C_1} \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right) \]

When we will use indirect to direct, the given or known count will be indirect and when we will use direct to indirect formula then given or known count will be direct.
Example 1.4:

Convert 70” woollen (grains) USA into Jute count.

Solution:

To convert from Direct to Direct system, we know that,

\[ C_2 = C_1 \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right) \]

\( L_1 = \) Length in known system, \( L_2 = \) Length in required system
\( W_1 = \) Weight in known system, \( W_2 = \) Weight in required system
\( C_1 = \) Count in known system, \( C_2 = \) Count in required system

\[ C_2 = 70 \times \left( \frac{1 \times 14400}{20 \times 7000} \right) \]

\[ C_2 = 70 \times 0.102 \]

\[ C_2 = 7.2 \text{ lbs/spindle} \]

Example 1.5:

Convert 20’s metric count into cotton count.

Solution:

To convert from Indirect to Indirect system, we know that,

\[ C_2 = C_1 \times \left( \frac{L_2}{L_1} \times \frac{W_2}{W_1} \right) \]

\( L_1 = \) Length in known system, \( L_2 = \) Length in required system
\( W_1 = \) Weight in known system, \( W_2 = \) Weight in required system
\( C_1 = \) Count in known system, \( C_2 = \) Count in required system

In cotton count length is 840 yards and weight is 1 lb, while in metric count length is 1000 meter and weight is 1 kg. So,
\[ C_2 = 20 \times \left( \frac{1000 \times 1.0936}{840} \times \frac{1}{1 \times 2.2046} \right) \]

Since, \( 1 \text{m} = 1.0936 \text{ yards}, 1 \text{kg}= 2.2046 \text{ lbs} \)

\[ C_2 = 20 \times 1.301 \times 0.4535 \]

\[ C_2 = 20 \times 0.590 \]

\[ C_2 = 11.8 \text{ s} \]

**Example 1.6:**

*Convert 10’s worsted count into woollen count.*

**Solution:**

To convert from Indirect to Indirect system, we know that,

\[ C_2 = C_1 \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

\( L_1 = \) Length in known system, \( L_2 = \) Length in required system

\( W_1 = \) Weight in known system, \( W_2 = \) Weight in required system

\( C_1 = \) Count in known system, \( C_2 = \) Count in required system

In worsted count hank length is 560 yards and weight is 1 lb, while in woollen count hank length is 256 yards and weight is 1 lb. So,

\[ C_2 = C_1 \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

\[ C_2 = 10 \times \left( \frac{560}{256} \times \frac{1}{1} \right) \]

\[ C_2 = 10 \times 2.18 \]

\[ C_2 = 21.8 \]

**Example 1.7:**

*Convert 10’s Linen count into English cotton count.*
Solution:

To convert from Indirect to Indirect system, we know that,

\[ C_2 = C_1 \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

\( L_1 \) = Length in known system, \( L_2 \) = Length in required system

\( W_1 \) = Weight in known system, \( W_2 \) = Weight in required system

\( C_1 \) = Count in known system, \( C_2 \) = Count in required system

In Linen count hank length is 300 yards and weight is 1 lb, while in Cotton count hank length is 840 yards and weight is 1 lb. So,

\[ C_2 = 10 \times \left( \frac{300}{840} \times \frac{1}{1} \right) \]

\[ C_2 = 10 \times [0.357] \]

\[ C_2 = 3.57 s \]

Example 1.8:

Convert 600 Denier count into Tex count.

Solution:

To convert from Direct to Direct system, we know that,

\[ C_2 = C_1 \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right) \]

\( L_1 \) = Length in known system, \( L_2 \) = Length in required system

\( W_1 \) = Weight in known system, \( W_2 \) = Weight in required system

\( C_1 \) = Count in known system, \( C_2 \) = Count in required system
We know that, in Denier count system length is 9000m and weight is 1 gram, while in Tex count system length is 1000m and weight is 1 gram.

\[
C_2 = C_1 \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right)
\]

\[
C_2 = 600 \times \left( \frac{1000}{9000} \times \frac{1}{1} \right)
\]

\[
C_2 = 66.6
\]

**Example 1.9:**

**Convert 20's Cotton count into Tex count.**

**Solution:**

To convert from Indirect to Direct system, we know that,

\[
C_2 = \frac{1}{C_1} \times \left( \frac{L_2}{L_1} \times \frac{W_1}{W_2} \right)
\]

$L_1 = \text{Length in known system}$,

$L_2 = \text{Length in required system}$

$W_1 = \text{Weight in known system}$,

$W_2 = \text{Weight in required system}$

$C_1 = \text{Count in known system}$,

$C_2 = \text{Count in required system}$

We know that, in Cotton count hank length is 840 yards and weight is 1 lb, while in Tex count system length is 1000m and weight is 1 gram.

\[
C_2 = \frac{1}{20} \times \left( \frac{1000}{1000} \times \frac{453.6}{1} \right)
\]

Since, 1 m = 0.1944 yards and 1 lb. = 453.6 grams

\[
C_2 = \frac{1}{20} \times \left( \frac{1000}{768.1} \times \frac{453.6}{1} \right)
\]
\[ C_2 = \frac{1}{20} \times 1.30 \times 453.6 \]

\[ C_2 = 29.52 \]

**Example 1.9:**

*Convert 30 Tex count into Cotton count.*

**Solution:**

To convert from Indirect to Direct system, we know that,

\[ C_2 = \frac{1}{C_1} \times \left( \frac{L_1}{L_2} \times \frac{W_2}{W_1} \right) \]

Let \( L_1 \) = Length in known system, \( L_2 \) = Length in required system

Let \( W_1 \) = Weight in known system, \( W_2 \) = Weight in required system

Let \( C_1 \) = Count in known system, \( C_2 \) = Count in required system

We know that, in Tex count system length is 1000m and weight is 1 gram, while in Cotton count hank length is 840 yards and weight is 1 lb,

\[ C_2 = \frac{1}{30} \times \left( \frac{1000}{768.1} \times \frac{453.6}{1} \right) \]

\[ C_2 = \frac{1}{30} \times 1.30 \times 453.6 \]

\[ C_2 = 19.68 \cong 20 \text{ s} \]
The count conversion for some mostly common systems is given below:

<table>
<thead>
<tr>
<th></th>
<th>Metric (Nm)</th>
<th>Cotton (Nec)</th>
<th>Worsted</th>
<th>Tex</th>
<th>Denier (den)</th>
<th>Decitex (dtex)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metric (Nm)</strong></td>
<td>1 × Nm</td>
<td>1.693 × Nec</td>
<td>1.129 × worsted</td>
<td>1000/tex</td>
<td>9000 / den</td>
<td>10000 / dtex</td>
</tr>
<tr>
<td><strong>Cotton (Nec)</strong></td>
<td>0.591 × Nm</td>
<td>1 × Nec</td>
<td>Worsted / 1.5</td>
<td>591/tex</td>
<td>5315 / den</td>
<td>5905 / dtex</td>
</tr>
<tr>
<td><strong>Worsted</strong></td>
<td>Nm / 1.129</td>
<td>1.5 × Nec</td>
<td>1 × worsted</td>
<td>886/tex</td>
<td>7972 / den</td>
<td>8858 / dtex</td>
</tr>
<tr>
<td><strong>Tex</strong></td>
<td>1000 / Nm</td>
<td>590.5 / Nec</td>
<td>885.5 / worsted</td>
<td>1 × tex</td>
<td>Den / 9</td>
<td>Dtex / 10</td>
</tr>
<tr>
<td><strong>Denier (den)</strong></td>
<td>9000 / Nm</td>
<td>5315 / Nec</td>
<td>7972 / worsted</td>
<td>9 × tex</td>
<td>1 × den</td>
<td>0.9 × dtex</td>
</tr>
<tr>
<td><strong>Decitex (dtex)</strong></td>
<td>10000 / Nm</td>
<td>5905 / Nec</td>
<td>8858 / worsted</td>
<td>10 × tex</td>
<td>1.11 × den</td>
<td>1 × dtex</td>
</tr>
</tbody>
</table>

### 1.4 Folded Yarn Count

The counts of folded yarns in cotton, linen and worsted are expressed in terms of the counts of the single threads of which the folded yarn is composed. There will be some contraction in length when two threads are twisted together; so that the actual count of single thread required producing a twofold yarn of 21s count will be slightly finer than 42s. But this contraction is not significant in ordinary cases.

To calculate the count of folded yarn, assume a definite length unit, say one hank. Then the weight of such length unit of each component threads is found out. The sum of these weights
will be the weight of the assumed length unit of resultant folded yarn. The length and weight being known; the count of the folded yarn can be easily calculated by using suitable formula as given below.

**For Indirect Count System**

\[
\frac{1}{R_c} = \frac{1}{R_1} + \frac{1}{R_2}
\]

And for ‘n’ number of yarn counts

\[
\frac{1}{R_c} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}
\]

**For Direct Count System**

\[
R_c = R_1 + R_2
\]

And for ‘n’ number of yarn counts

\[
R_c = R_1 + R_2 + \ldots + R_n
\]

Where, \(R_1\), \(R_2\), and \(R_c\) are the count of 1st individual, 2nd individual and resultant yarns respectively.

Note: The counts should be in same system.

---

**Example 1.10:**

*Calculate the resultant count of three-fold cotton yarn consists of 20”, 30” and 15”.*

**Solution:**

1 hank of 20” = 1/20 lb.

1 hank of 30” = 1/30 lb.

1 hank of 15” = 1/15 lb.

So, for three-fold yarn:
1 hank of three fold yarn = \( \frac{1}{20} + \frac{1}{30} + \frac{1}{15} = \frac{9}{60} \) lbs

Therefore, the resultant count three-fold yarn

\[
\text{Resultant count} = \left[ \frac{1}{\text{Weight in lbs of 1 hank of three fold yarn}} \right] \\
= \left[ \frac{1}{9/60} \right] \\
\text{Resultant count} = 6.66 \approx 7' \text{ s}
\]

**Example 1.11:**

*A two-fold cotton yarn having 8° and a thread of unknown count was found to be of 4° cotton. Find the unknown count of yarn.*

**Solution:**

1 hank of 8° = 1/8 lb.

1 hank of two-fold yarn = 1/4 lb.

Therefore, 1 hank of unknown yarn

\[1 \text{ hank of unknown yarn} = \frac{1}{4} - \frac{1}{8} = \frac{1}{8} \text{ lbs}\]

Count of unknown yarn = \[\left[ \frac{1}{\text{Weight in lb. of 1 hank of unknown yarn}} \right] \]

\[= \left[ \frac{1}{1/8} \right] \]

\[= 8' \text{ s Cotton} \]

1.5 **Cost of Folded yarn**

The end price of folded yarns depends upon the cost of its every component yarns. If the constituent yarns are of same count, the calculation will be very simple and easy. But if the folded yarn is composed of yarns of different counts, the cost of the resultant yarn count will depend upon the proportion of the constituent yarns in the folded yarn.
If two yarns are folded together, and

A = Count of 1\textsuperscript{st} yarn
B = Count of 2\textsuperscript{nd} yarn
y = Cost of 1\textsuperscript{st} yarn
z = Cost of 2\textsuperscript{nd} yarn

Cost of folded yarn (material) = \( C_f = \frac{Az + By}{A + B} \)

In case of three yarns, folded together,

A = Count of 1\textsuperscript{st} yarn
B = Count of 2\textsuperscript{nd} yarn
C = Count of 3\textsuperscript{rd} yarn
y = Cost of 1\textsuperscript{st} yarn
z = Cost of 2\textsuperscript{nd} yarn
w = Cost of 3\textsuperscript{rd} yarn

Cost of folded yarn (material) = \( C_f = \frac{ABw + ACz + BCy}{AB + AC + BC} \)

Total cost of folded yarn, \( C_f' = C_f + \text{Conversion/folding cost} \)

\[ C_f' = C_f + C_C \]

Example 1.12:

Calculate the price per pound of two fold yarn by twisting together 20\textsuperscript{ns} and 30\textsuperscript{ns}. Price of 20\textsuperscript{ns} and 30\textsuperscript{ns} per pound is Rs-18 and Rs-35 respectively. The doubling cost per pound is Rs-2.

Solution:

If,
A= Count of 1st yarn
B= Count of 2nd yarn
y= Cost of 1st yarn
z= Cost of 2nd yarn

Cost of folded yarn material can be calculated as under:

\[ C_f = \frac{Az + By}{A + B} \]

\[ C_f = \frac{(20 \times 35) + (30 \times 18)}{(20 + 30)} \]

\[ C_f = \frac{700 + 540}{50} \]

\[ C_f = 32.2 \]

Total cost of folded yarn is:

\[ C_f' = C_f + C_c \]

\[ C_f' = 32.2 + 2 = 34.2 \text{ Rs.} \]

1.6 Conditioning

All textile materials are more or less hygroscopic. They contain a certain amount of moisture, depending on the relative humidity of the surrounding atmosphere in which they are kept. So in determining the weight of the yarn or a fabric it is necessary to have the weight taken under standard condition. Also while selling or purchasing cotton yarn their price is fixed on their conditioned weight. While doing the textile materials business, one should know about the moisture regain (MR) and moisture content (MC) of the material. The amount of moisture absorbed by the oven dry weight of the material when exposed to the atmosphere is called as moisture regain of the material.

\[ Moisture \text{ Regain (MR)}\% = \frac{Original \text{ weight} - Oven \text{ dry weight}}{Oven \text{ dry weight}} \times 100 \]

While the amount of moisture contained in a material and is expressed as percentage on its original weight is called moisture content.
Moisture content (MC)\% = \frac{Original\ weight - Oven\ dry\ weight}{Original\ weight} \times 100

The most important term for doing business in textile is the conditioned weight (correct invoice weight) of the material. If there is less moisture in the cotton than the normal, the buyer will be gainer and seller will be loser to an extent depending upon the deficiency of the cotton in respect of moisture content. To avoid this problem while doing business of the materials like: cotton, their price is fixed on conditioned weight.

\[ Conditioned\ weight\ of\ yarn = W_C = W_O + \left(\frac{MR\%}{100} \times W_o\right) \]

\( W_o = \) Oven dry weight (The weight of the material obtained by heating the material in a conditioning oven at 220-230 F, until it attains the constant weight).

**Example 1.13:**

*The oven dry weight of 690 yards of cotton yarn is 45 grains. What is the conditioned count of the yarn?*

**Solution:**

We know that,

\[ Conditioned\ weight\ of\ yarn, W_C = W_O + \left(\frac{MR\%}{100} \times W_o\right) \]

Conditioned weight of yarn, \( W_C = 45 + \left(\frac{8.5}{100} \times 45\right) \)

Conditioned weight of yarn, \( W_C = 45 + 3.82 \)

Conditioned weight of yarn, \( W_C = 48.82\ grains \)

**Example 1.14:**

*The oven dry weight of the 220 grains of cotton is found to be 200 grains. Calculate the moisture regain, moisture content and conditioned weight of the cotton.*
Solution:

\[ \text{Moisture Regain (MR)}\% = \frac{\text{Original weight} - \text{Oven dry weight}}{\text{Oven dry weight}} \times 100 \]

\[ \text{Moisture Regain (MR)}\% = \frac{220 - 200}{200} \times 100 \]

\[ \text{Moisture Regain (MR)}\% = \frac{20}{200} \times 100 \]

\[ \text{Moisture Regain (MR)} = 10 \% \]

\[ \text{Moisture content (MC)}\% = \frac{\text{Original weight} - \text{Oven dry weight}}{\text{Original weight}} \times 100 \]

\[ \text{Moisture content (MC)}\% = \frac{220 - 200}{220} \times 100 \]

\[ \text{Moisture content (MC)}\% = \frac{20}{220} \times 100 \]

\[ \text{Moisture content (MC)} = 9.09 \% \]

\[ \text{Conditioned weight of yarn, } W_C = W_0 + \left( \frac{\text{MR}}{100} \times W_0 \right) \]

\[ \text{Conditioned weight of yarn, } W_C = 200 + \left( \frac{8.5}{100} \times 200 \right) \]

\[ \text{Conditioned weight of yarn, } W_C = 200 + 17 \]

The different textile materials have different moisture regain and moisture content as given below.

Table 1.2 Moisture Regain and Moisture Content of Different Fibers

<table>
<thead>
<tr>
<th>Material Name</th>
<th>Moisture Regain %</th>
<th>Moisture Content %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>8.5</td>
<td>7.83</td>
</tr>
<tr>
<td>Flax, Hemp</td>
<td>12</td>
<td>10.7</td>
</tr>
<tr>
<td>Jute</td>
<td>13.75</td>
<td>12.1</td>
</tr>
<tr>
<td>Silk</td>
<td>11</td>
<td>9.91</td>
</tr>
<tr>
<td>Viscose Rayon</td>
<td>11</td>
<td>9.91</td>
</tr>
</tbody>
</table>
### Rayon Acetate

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>5.66</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Worsted (Yarn)</th>
<th>18.25</th>
<th>15.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Woollen (Yarn)</td>
<td>17</td>
<td>14.5</td>
</tr>
<tr>
<td>Nylon</td>
<td>4.2</td>
<td>3.78</td>
</tr>
</tbody>
</table>

#### 1.7 Average Count

The term average count indicates the calculated count determined from the total length and total weight of the different counts of yarn in question. And by this total length and total weight we can find the average count in the required system.

**Example 1.15: Calculate the average count of 80/S, 50/S, 40/S and 20/S cotton yarn.**

**Solution:**

\[ C_1:C_2:C_3:C_4 \]

80:50:40:20

Taking L.C.M. of all four counts,

\[ \text{L.C.M} = 400 \]

This means we have to take 400 hanks of each count.

\[ 400 \text{ hanks of } 80/S \text{ weighs } = \frac{\text{Length(hanks)}}{\text{Count}} = \frac{400}{80} = 5 \text{ lbs} \]

\[ 400 \text{ hanks of } 50/S \text{ weighs } = \frac{\text{Length(hanks)}}{\text{Count}} = \frac{400}{50} = 8 \text{ lbs} \]

\[ 400 \text{ hanks of } 40/S \text{ weighs } = \frac{\text{Length(hanks)}}{\text{Count}} = \frac{400}{40} = 10 \text{ lbs} \]

\[ 400 \text{ hanks of } 20/S \text{ weighs } = \frac{\text{Length(hanks)}}{\text{Count}} = \frac{400}{20} = 20 \text{ lbs} \]

Now, \( \text{Total number of hanks} = 400+400+400+400=1600 \text{ hanks,} \)
Total weight = 5 + 8 + 10 + 20 = 43 lbs

And,

\[ \text{Average count} = \frac{\text{Length (hanks)}}{\text{Weight (lbs)}} = \frac{1600}{43} = 37.25 \]

1.8 Exercise

Problem 1: Show that 1 oz = 28.3 gms.
Problem 2: Show that 1 oz/yd^2 = 33.9 grams/m^2.
Problem 3: Show that 1 lb/in^2 = 0.06895 bar
Problem 4: Show that in indirect system \( N_{ec} = 8.33 \times \frac{L(\text{yards})}{W(\text{grains})} \)
Problem 5: Show that in indirect system \( N_{ews} = 12.5 \times \frac{L(\text{yards})}{W(\text{grains})} \)
Problem 6: Show that in indirect system \( Nm = \frac{L(\text{Kms})}{W(\text{Kgs})} = \frac{L(\text{Mtrs})}{W(\text{Grms})} \)
Problem 7: Show that in indirect system \( N_{efr} = \frac{1}{2} \times \frac{L(\text{Mtrs})}{W(\text{Grms})} \)
Problem 8: If 240 yards of cotton yarn weight 40 grains, what is the count of yarn in English cotton system?
Problem 9: Find the weight of 270 yards of 60S cotton.
Problem 10: What is length of 105 grains of 40S cotton yarn?
Problem 11: How many hanks are contained in 5 bundles of 80S cotton yarn?
Problem 12: Find the count in worsted system of yarn if 650 m weigh 55 grains.
Problem 13: If 840 yards of worsted yarn weigh 50 grains. What will be the count of yarn?
Problem 14: The weight of 768 yards of woollen yarn is 0.25 lbs. What is the count of yarn?
Problem 15: Calculate the count in French cotton system of 100 m of cotton yarn if weight is 4 grams.
Problem 16: If the weight of 60 km of cotton yarn is 5 kgs. What is the count of yarn in French cotton and metric system?
Problem 17: 45 yards of cotton was found to be weigh 5 grains. Calculate its count in decimal system?
Problem 18: Show that in direct system \( Tex \, Count = Tex = 1000 \times \frac{W(\text{Grms})}{L(\text{Mtrs})} \)
Problem 19: Show that in direct system \( Denier \, count = Denier = 9000 \times \frac{W(\text{Grms})}{L(\text{Mtrs})} \)
Problem 20: If 350 meters of silk yarn weigh 7.5 grains. What is the count of yarn in denier system?
Problem 21: What is the weight of 270 meter of Nylon yarn whose count is 200 denier.
Problem 22: Calculate the count of 5000 yards of cotton yarn in Tex system, if its weight is 10 ounces.
Problem 23: The length of a quality of 42 Tex Nylon is 7 Km. Calculate the weight of yarn in ounces?
Problem 24: If 27432 yards of acetate yarn weight 240 grams. What is its count in Tex and Grex system?
Problem 25: Find the length of 40 ounces & 11 drams of silk yarn, whose count is 150 drams.
Problem 26: Show that, Linen count = 0.853 × Woollen count
Problem 27: A warp is composed of 40/2 and 30/1 cotton yarn in proportion of 2 ends of 40/2 & 12 ends of 30/1 yarn. Calculate the average count of yarn in warp.
Problem 28: A warp consists of yards of following particulars. Calculate the average count; (a) 3 lbs of 20 s yarn. (b) 6 lbs of 16 s yarn. (c) 9 lbs of 24 s yarn.
Problem 29: Given a compound twisted thread, which is made up of one thread of 20 Ne spun viscous, one thread of 20/2 ply Ne worsted & one thread of 80 denier polyester filament yarn. Find the resultant yarn count in the Tex, denier & cotton system.
Problem 30: If the oven dry weight of 7200 yards of Jute yarn is 2 lbs. then calculate its conditioned count (direct system). The percentage of M.R of Jute is 13.75%.
Problem 31: Convert 20s cotton into Worsted system.
Problem 32: Convert 135 denier into Tex count.
Problem 33: Calculate the equivalent count of 163 Tex into Grex system.
Problem 34: Convert 100s cotton into Denier system.
Problem 35: Convert 20 Tex into Worsted count.
Problem 36: Show that for cotton count \( N_e = \frac{5315}{\text{Denier}} \)
Problem 37: Show that \( N_e = 0.59N_m \)
Problem 38: Calculate the counts of 3 fold cotton yarn composed of 20/1, 15/1 and 12/1.
Problem 39: One thread of an unknown count, when folded together with another 72/1 cotton yarn gives a twofold yarn of 31.5 cotton. Calculate the count of unknown thread.
Problem 40: A 3-fold cotton yarn is composed of 8s, 24s & a thread of un-known count was found to be a 4s cotton. Calculate the count of unknown thread.
Problem 41: Calculate the count of the corkscrew yarn produced by twisting together one thread of 2/40s and the other of 10s cotton. By actual measurement it was found that 20 inches of 10s thread and 10 inches of 2/40s are contained in 10 inches of corkscrew yarn.
Problem 42: A yarn of 36/1 costs 42Rs/lb & 12/1 yarn costs 14 Rs/lb. What is the cost of yarn composed of two twisted threads?
Problem 43: Find the cost of 3 folded yarn composed of 60/1, 40/1 & 20/1 & cost of yarn/lb is 32, 24 & 16Rs/lb respectively. If folding cost is 55 Rs/lb.
Problem 44: Calculate the cost of 4 ply yarn of 80s, 60s, 50s & 40s yarn. If their cost is 40, 36, 32 & 24 Rs/lb. If folding/conversion cost is 0.85 Rs/lb.
Problem 45: A folded yarn is composed of one thread of 14 Tex & other of 12 Tex. Their price is Rs9 & Rs 10 per pound respectively. Calculate the cost of folded yarn, if conversion cost is 0.35 Rs/kg.
Problem 46: The conditioned count of a yarn is 20, cotton. What is the oven dry weight of 16 hanks of such yarn?

Problem 47: Calculate the conditioned count of cotton yarn in Tex system, if oven dry weight of 24 km yarn is 32 grams.
2. **Winding**

Winding is a process in which yarn from ring bobbins (comes from spinning department) are wound into convenient form of package. Transferring a yarn from one type of package to another package, more suitable for subsequent process is also called winding. Main objectives of winding include:

- Changing package size/shape according to requirement of subsequent process
- Clearing yarn defects like slub, thick and thin places, neps, etc
- Doubling the yarn

### 2.1 Winding Rate

Winding rate is the speed at which the yarn is wound on package surface. In case of parallel package, the traverse is very slow, so the winding rate is approximately equal to the surface speed (πDN). But in case of cross wound package, where traverse is quick, its effect on winding rate must be taken into account. In this case, the surface speed and traverse speed of yarn both contribute to the actual winding rate.
Figure 2.1 Traverse and Surface velocity in case of cross wound package

The traverse velocity \(V_T\) is at right angles to surface velocity \(V_S\), as shown in Figure 2.1. Vector addition of both these velocities produces the resultant winding velocity \(V_R\). Let,

\[
\begin{align*}
AB &= \text{Traverse speed of yarn, } V_T \\
OB &= \text{Surface speed of drum, } V_S \\
OA &= \text{Resultant speed of yarn, } V_R
\end{align*}
\]

Then,

\[
(OA)^2 = (OB)^2 + (AB)^2
\]
\[
V_R^2 = V_S^2 + V_T^2 \quad \text{..............Eq. 2.1}
\]

If, 

\[
D = \text{Diameter of grooved drum,} \\
N = \text{RPM of drum}
\]

Then,

\[
V_S = \pi DN
\]

Putting values of \(V_S\) in Eq.2.1, we get

\[
V_R^2 = (\pi DN)^2 + V_T^2
\]
\[
V_R = \sqrt{(\pi DN)^2 + V_T^2} \quad \text{.............. Eq. 2.2}
\]

Example 2.1:

Consider a grooved drum having two grooves, is driving package. If diameter of drum is 8 cm and it is revolving at 900 rpm, calculate the winding rate, \(V_R\).

Solution:
Since the number of grooves in drum are 2, its traverse will complete in 2 revolutions.

- Traverse if 2 rev/min of drum = 6" / min
- Traverse if 1 rev/min of drum = 3" / min
- Traverse if 900 rev/min of drum = 3 × 900 = 2700" / min
- Traverse if 900 rev/min of drum = 2700/39.37 = 69 m/min

\[
V_R = \sqrt{(\pi DN)^2 + V_T^2}
\]

\[
V_R = \sqrt{(3.1416 \times 0.08 \times 900)^2 + (69)^2}
\]

\[V_R = 237 \text{ m/min}\]

### 2.2 Coil angle and wind angle

The angle at which yarn coils around the package, relative to the vertical axis is known as winding angle (\(\theta\)) as shown in Figure 2.2. Lesser the winding angle, more compact will be the package.
Angle of wind, $\theta$ can be calculated as:

$$\tan \theta = \frac{AB}{OB} = \frac{V_T}{V_S}$$

$$\theta = \tan^{-1} \left( \frac{V_T}{V_S} \right) \ldots \ldots \text{Eq. 2.3}$$

The angle of wind reduces with increase in diameter of package, as yarn traverses from tip towards the base.

The angle b/w the direction of yarn lay on the package surface and the plane parallel to package axis is called coil angle, denoted by $\alpha$.

Coil angle, $\alpha = 90 - \theta$

**Example 2.2:**

*A cylindrical package is wound on 5 cm diameter of paper cone. Spindle speed is 3200 rpm. Its traverse velocity is 205 m/min. Determine net winding rate and angle of wind as start of winding and net winding rate and wind angle at package diameter of 16 cm.*

**Solution:**

The problem needs to be solved at two different levels, initially when the diameter of cone is almost equal to the paper cone and secondly for the final stage, where the diameter of cone is maximum.
When the diameter is equal to 5 cm:

\[ D_1 = 5 \text{ cm} = 0.05 \text{ m} \]
\[ N = 3200 \text{ rpm} \]
\[ V_{S1} = \pi D_1 N = 502.4 \text{ m/min} \]
\[ V_T = 205 \text{ m/min} \]
\[ \theta_1 = \tan^{-1} \left( \frac{V_T}{V_{S1}} \right) = \tan^{-1} \left( \frac{205}{502.4} \right) \]
\[ \theta_1 = 22^\circ 10' \]

When the diameter is equal to 16 cm:

\[ D_2 = 16 \text{ cm} = 0.16 \text{ m} \]
\[ N = 3200 \text{ rpm} \]
\[ V_{S2} = \pi D_2 N = 1607.7 \text{ m/min} \]
\[ V_T = 205 \text{ m/min} \]
\[ \theta_2 = \tan^{-1} \left( \frac{V_T}{V_{S2}} \right) = \tan^{-1} \left( \frac{205}{1607.7} \right) \]
\[ \theta_2 = 7^\circ 16' \]

From the results, it can be observed that the wind angle is reducing as diameter of package is increasing. So, the resultant speed in each case may be calculated as:

**\( \text{V}_R \) when diameter is 5 cm:**

\[ \sin \theta_1 = \frac{V_T}{V_{R1}} \]
\[ V_{R1} = \frac{V_T}{\sin \theta_1} = \frac{205}{\sin (22^\circ 10')} \]
\[ V_{R1} = 554 \text{ m/min} \]

**\( \text{V}_R \) when diameter is 16 cm:**

\[ \sin \theta_2 = \frac{V_T}{V_{R2}} \]
\[ V_{R2} = \frac{V_T}{\sin \theta_2} = \frac{205}{\sin (7^\circ 16')} \]
\[ V_{R2} = 1626 \text{ m/min} \]
The percentage increase in the speed is calculated as:

$$ \text{Percentage increase at start of package} = \frac{(V_{R1} - V_{S1})}{V_{S1}} $$

Percentage increase at start of package = \( \frac{554 - 503}{503} = 10\% \)

$$ \text{Percentage increase at end of package} = \frac{(V_{R2} - V_{S2})}{V_{S2}} $$

Percentage increase at end of package = \( \frac{1628 - 1608}{1608} = 1\% \)

2.3 Winding machine production

The production of winding machine is usually expressed in terms of amount of yarn wound per unit time. It is measured in terms of weight, e.g. Kgs, lbs or bags (1 bag = 100 lbs), it is the net yarn weight excluding core weight, stoppers and packing material.

The production of winding machine can be determined by the following formula.

$$ P = \frac{W \times 60 \times T \times E \times S \times 1.0936}{N_e \times 840} \times 100 \quad \text{Eq. 2.4} $$

Where,

- \( P \) = Production (lbs)
- \( W \) = Winding rate (m/min) = Surface speed of drum
- \( T \) = Time (hours)
- \( E \) = Efficiency
- \( S \) = No of spindles
- \( N_e \) = Count

The winding machine efficiency gives us an idea about the running time and stoppages of the machine. It can be calculated as:

$$ P = \frac{\text{Actual Production}}{\text{Calculated Production}} \times 100 \quad \text{Eq. 2.5} $$

The production of winding machine depends upon a number of factors. The most important factors are the diameter and RPM of drum. The yarn count also affects the production
in terms of weight. Other factors include quality of yarn, degree of clearing, splicing frequency and the environmental conditions.

**Example 2.3:**

*We are to wind a yarn of 10/s into cones of 4.167 lbs, using a single winder. The diameter of drum is 2.5” and it is revolving at 1000 rpm. Calculate the production in lbs/hour if efficiency is 90%.*

**Solution:**

Surface speed of drum = \( \pi dN \) = 3.14 x 2.5” x 1000 = 7854 “/min

Surface speed of drum = \((7854 \times 60)/36 = 13090\) yards/min

Production in lbs/hr = \(13090/(840 \times 10) = 1.56\) lbs

As the efficiency is 90%, so

Production in lbs/hr = \((1.56 \times 90)/100 = 1.4\) lbs

**2.4 Package density**

Density of a winding package is the measure of its hardness or softness. It is mass of yarn wound per unit volume. The hardness of successive layers (from inside to outside of package) must decrease gradually. Optimum density is required for the wound packages. The density of a package may be determined as follow.

Diameter of package at base = \(D_1\)

Diameter of paper at base = \(D_2\)

Diameter of package at tip = \(d_1\)

Diameter of paper at tip = \(d_2\)

Height of yarn on package = \(h\)

The volume of yarn on a tapered package can be calculated as:
\[ \text{Volume of frustum} = \frac{\pi h}{12} \left\{ (D_1^2 + D_1 d_1 + d_1^2) - (D_2^2 + D_2 d_2 + d_2^2) \right\} \]

In case of parallel package, the volume of yarn is calculated as:

\[ \text{Volume of yarn on parallel package, } V = \frac{\pi}{4} (D^2 - d^2) L \]

Where,

- Diameter of package = D
- Diameter of paper = d
- Height of yarn on package = h

If \( W_1 \) is the weight of paper and \( W_2 \) is the weight of package, then weight of yarn on package is \( W_2 - W_1 \). Thus density can be calculated as:

\[ \text{Density (g/cm}^3\text{)} = \frac{\text{Weight in grams}}{\text{Volume in cm}^3\text{}} \]

The cones used in high speed warping or for shuttle less weaving should be tapered at certain angles i.e., 6° for high take-off speed of yarn. There is variation in diameter of paper cone. Diameter at base is higher than the tip of paper cone. So, there is variation in the surface speed of cone. The winding rate at the base will be faster than tip of the core, to keep constant speed of yarn; traverse is kept faster toward the tip of cone.

**Example 2.4:**

Show that the traverse speed in a taper package increases with decrease in the diameter of cone.

**Solution:**

Consider a conical package having two equally wide stripes A & B with diameters of D1 & D2. Let, the length of yarn wound across stripes A and B is represented by ‘a’ and ‘b’ respectively. To construct a package at uniform rates in two stripes the quantity of yarn (length of yarn lay) must be proportional to \( D_1 \) and \( D_2 \).
So,

\[ a \propto D_1 \]

\[ a = \text{constant} \times D_1 \]

\[ a / D_1 = \text{constant} \ldots \ldots \text{(a)} \]

Similarly,

\[ b \propto D_2 \]

\[ b = \text{constant} \times D_2 \]

\[ b / D_2 = \text{constant} \ldots \ldots \text{(b)} \]

Comparing the equation (a) and (b)

\[ a / D_1 = b / D_2 \]

It means the ratio between the yarn lay should be equal to the ratio of diameters of respective stripe. Let,

\[ D_1 = 10 \text{ cm} \]

\[ D_2 = 8 \text{ cm} \]

\[ a = 3 \text{ cm} \]

Then,

\[ b = a \times (D_2 / D_1) \]

\[ b = 3 \times (10 / 8) \]

\[ b = 2.4 \text{ cm} \]
If \( \theta_1 \) and \( \theta_2 \) are the wind angles for yarn lay ‘a’ and ‘b’, then in triangle OAB,

\[
\sin \theta_1 = \frac{AB}{OA} = \frac{1}{3}
\]

\[
\theta_1 = \sin^{-1} \left( \frac{1}{3} \right) = 19.47°
\]

If \( V_T \) is the traversing speed of yarn across stripe A and \( V_s \) is the surface speed of package at A, then,

\[
\tan \theta_1 = \frac{V_T}{V_s}
\]

\[
V_T = V_s \cdot \tan \theta_1
\]

\[
V_T = \pi DN \cdot \tan (19.47°)
\]

\[
V_T = 3.14 \times 10 \times N \cdot \tan (19.47°)
\]

\[
V_T = 11.09 \times N \text{ cm/min}
\]
\[ \sin \theta_2 = \frac{A'B'}{OA'} = 1/2.4 \]

\[ \theta_2 = \sin^{-1} \left( \frac{1}{2.4} \right) = 24.62^\circ \]

Here if \( V_T \) is the traversing speed of yarn across stripe B and \( V_S \) is the surface speed of package at B, then

\[ V_T = V_S \cdot \tan \theta_2 \]

\[ V_T = \pi DN \cdot \tan \theta_2 \]

\[ V_T = 3.14 \times 10 \times N \cdot \tan (24.62^\circ) \]

\[ V_T = 14.39 \times N \text{ cm/min} \]

This result shows that the traverse speed \( (V_T) \) and wind angle \( (\theta) \) increases towards the tip of the package as the diameter \( (D) \) of package reduces.

Similarly, we can also find the traverse speed at diameters of 12cm, 10cm, 8cm and 6cm, as are given in Table 2.1.

<table>
<thead>
<tr>
<th>Cone Section Dia (cm)</th>
<th>Angle of Wind ((\theta))</th>
<th>Coil Angle ((90-\theta=\alpha))</th>
<th>Traverse Velocity, (V_T) (cm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>16° - 8 sec</td>
<td>73° - 52 sec</td>
<td>10.89 n</td>
</tr>
<tr>
<td>10</td>
<td>19° - 27 sec</td>
<td>70° - 33 sec</td>
<td>11.09 n</td>
</tr>
<tr>
<td>8</td>
<td>24° - 37 sec</td>
<td>65° - 23 sec</td>
<td>11.50 n</td>
</tr>
<tr>
<td>6</td>
<td>33° - 45 sec</td>
<td>56° - 15 sec</td>
<td>12.60 n</td>
</tr>
</tbody>
</table>
The above table shows that the traverse velocity increases towards the nose (tip) of the cone. Therefore, the grooves cut into the driving drum of a cone winder have increasing pitch from the larger end of cone to the nose of cone.

Table 2.2 Relation b/w the cone section diameter & Cos of coil angle:

<table>
<thead>
<tr>
<th>Cone Section Dia (cm)</th>
<th>Cosine of coil Angle (Cos α)</th>
<th>D. Cos α</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Cos74° = 0.28</td>
<td>3.36</td>
</tr>
<tr>
<td>10</td>
<td>Cos70° = 0.33</td>
<td>3.34</td>
</tr>
<tr>
<td>8</td>
<td>Cos65° = 0.42</td>
<td>3.35</td>
</tr>
<tr>
<td>6</td>
<td>Cos56° = 0.56</td>
<td>3.34</td>
</tr>
</tbody>
</table>

This result shows that Cone section diameter × cos of coil angle = constant

Table 2.3 Relation b/w traverses speed & Sin of coil angle:

<table>
<thead>
<tr>
<th>Traverse Velocity, V_T (cm/min)</th>
<th>Sine of coil Angle (Sin α)</th>
<th>V_T. Sin α</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.90 n</td>
<td>Sin74° = 0.96</td>
<td>10.47 n</td>
</tr>
<tr>
<td>11.09 n</td>
<td>Sin70° = 0.94</td>
<td>10.46 n</td>
</tr>
<tr>
<td>11.52 n</td>
<td>Sin65° = 0.90</td>
<td>10.47 n</td>
</tr>
<tr>
<td>12.60 n</td>
<td>Sin56° = 0.83</td>
<td>10.47 n</td>
</tr>
</tbody>
</table>

This result shows that at any cone section, traverse velocity × sin of coil angle = constant
2.5 Exercise

Problem 1: A spinning unit has a winding machine with 80 spindles; the drum diameter of each is 6 cm. Calculate the number of bags produced in one day, if the yarn count is 20/s and drum RPM are 1147 rpm, machine is operating at 92.5% efficiency.

Problem 2: Calculate the time required to produce 200 bags of 16/s, if the installed capacity is 100 spindles, drum diameter is 3” and it is revolving at 1200 rpm at an efficiency of 90%.

Problem 3: Find the number of spindles required to give a production of 800 kgs in 24 hours, where yarn count is 12/s, drum diameter 2.5”, drum rpm 1250 and efficiency is 90%.

Problem 4: How many spindles will be required to get a daily production of 1000 lbs in, if the yarn count is 20/s, drum diameter is 3”, drum rpm 1150 and expected efficiency of machine is 95%.

Problem 5: How many hours will be required to wind 100 bags of 30/s, if the installed capacity is 140 spindles, drum diameter is 6 cm and it is revolving at 1100 rpm at an efficiency of 92%.

Problem 6: Calculate the efficiency of a winding machine with 80 spindles; the drum diameter of each is 3”, yarn count is 40/s and drum RPM are 1150 rpm, the per shift production is 650 lbs.

Problem 7: What will be the per day production of a spinning unit (in bags) having 120 spindles. The drum diameter and RPM are 2.5 inch and 1050 respectively. The yarn count is 24/s and machine is operating at 90% efficiency.

Problem 8: Calculate the time in hours required to convert a bag of 16/s, with individual cone weight of 4.16 lbs into baby cones of 1 lbs each. The available number of spindles is 16, drum diameter is 3” and it is revolving at 1200 rpm at an efficiency of 93%.

Problem 9: Find the number of spindles required to give per shift production of 450 lbs in 24 hours, where yarn count is 40/s, drum diameter 2.5”, drum rpm 1000 and average efficiency is 90%.

Problem 10: How many spindles will be required to get a daily production of 700 lbs, if the yarn count is 30/s, drum diameter is 7 cm, drum rpm 1150 and expected efficiency of machine is 85%.
Problem 11: How many hours will be required to wind 200 lbs of 60/s, if the installed capacity is 40 spindles, drum diameter is 2.5 cm and it is revolving at 1100 rpm at an efficiency of 90%.

Problem 12: Calculate the efficiency of a winding machine with 100 spindles; the drum diameter of each is 3”, yarn count is 30/s and drum RPM are 900 rpm. The per day production is 1250 lbs.

Problem 13: Calculate the winding machine efficiency having 120 100 spindles; where drum diameter of each is 2.5”, yarn count is 24/s and drum RPM are 950 rpm. The per day production is 1500 lbs.
3. **Warping**

Warping is the process of transferring a number of yarns from a creel of single end packages, forming a parallel sheet, on to a beam. The main objectives of warping include:

- To get the required number of ends as per set calculation
- To get the required length of yarn on each beam of the set
- To wind a specific type of package required by subsequent process

The most commonly used types of warping include direct/high speed warping, sectional warping and ball warping.

3.1 **Direct warping**

In direct warping, the yarns are withdrawn from the single-end yarn packages on the creel and directly wound on a beam. It is a single step and high speed process.
3.1.1 Set calculations
The set calculations involve the warp count, length of warp, number of ends in warp, weight of warp, number of creels, cone weight and number of beams.

A formula to calculate the approximate number of total ends in weaver beam is given below; the detailed formula is given later in chapter 6.

\[
\text{Total ends in weaver's beam} = \frac{\text{Ends/inch} \times \text{Fabric width (inch)} \times \text{No of width}}{\text{No of weaver's beam}}
\]

The number of warper beams is calculated as:

\[
\text{No. of warper beams} = \frac{\text{Total ends}}{\text{Creel capacity}}
\]

\[
\text{No. of ends/warper beam} = \frac{\text{Total Ends}}{\text{No of warper beams}}
\]

Next step in set calculations is to calculate the cone length, using warp count and the cone weight. This calculation is necessary to calculate exactly the set length.

\[
\text{Cone length (meters)} = \frac{\text{Warp count} \times \text{Cone weight (lbs)} \times 840}{1.0936}
\]

The length taken from cone is calculated by subtracting remainders from cone length.

\[
\text{Length Taken} = \text{Cone Length} - \text{Cone remainder}
\]

\[
\text{Length taken %age} = \left(\frac{\text{Length taken from cone (meters)}}{\text{Cone length (meters)}}\right) \times 100
\]

Note: Normally the length taken %age is 99% for single yarns.

Now the set length is calculated using the below relation.

\[
\text{Set length (meters)} = \frac{\text{Length taken (meters)}}{\text{No of warper beams}} \times \text{No of creels}
\]

The number of creels may be 1, 2, 3 or 4 depending on the requirement of set length. The amount of yarn in terms of bags, required to warp a set of known parameters is:

\[
\text{No. of bags} = \frac{\text{Total ends} \times \text{No. of creels}}{\text{No. of beams} \times \text{Cones/bag}}
\]
Beam count is the term used to express the count of yarn calculated using the collective amount of yarn warped on the beam.

$$\text{Beam Count} = \frac{\text{Set Length (meters)} \times \text{Ends/beam} \times 1.0936}{\text{Actual beam weight (lbs)} \times 840}$$

The length short loss in terms of weight and percentage is calculated as:

$$\text{Length Short loss (lbs)} = \frac{\text{Length short (meters)} \times \text{Total no of cones} \times 1.0936}{\text{Warp count} \times 840}$$

$$\text{Length Short loss (\%)} = \frac{\text{Length short (meters)}}{\text{Set Length (meters)}} \times 100$$

**Example 3.1:**

Perform set calculations separately for 1, 2, 3 and 4 creels set for the quality: 30 × 30 / 91 × 86, 65”, that will be produced on 190cm loom. The cone weight is 4.167 lbs and cone remainder is 960 meters, while creel capacity used is 740.

**Solution:**

Set Calculation for 1 Creel:

$$\text{No. of widths} = \frac{\text{Loomwidth}}{\text{Clothwidth}} = \frac{74.80}{65} = 1.15 \cong 1 \text{ width}$$

$$\text{Total ends in weaver’s beam} = \frac{\text{Ends/inch} \times \text{width}^2 \times \text{No of width}}{\text{No of weaver’s beam}}$$

$$\text{Total ends in weaver’s beam} = \frac{91 \times 65 \times 1}{1} = 5915 \text{ ends}$$

$$\text{No. of Warper beam} = \frac{\text{Total ends}}{\text{Creel capacity}} = \frac{T.E}{C.C} = \frac{5915}{740} = 7.99 \cong 8$$

$$\text{No. of Ends/warper beam} = \frac{\text{Total ends}}{\text{No of warper beams}} = \frac{5915}{8} = 739.375$$

Now it can be 739 ends/beam or 740 ends/beam. To calculate it we will take the figure after decimal point and multiply it with total number of beams.

$$0.375 \times 8 = 3 \text{ beams}$$

So, three beams out of 8 will be of 740 ends and remaining beams will be of 739 ends and by their sum we will get our required number of ends for a set.
740 × 3 = 2220 ends

739 × 5 = 3695 ends

Total ends = 5915

Next step is the calculation of length available on the cone of given weight and ultimately the calculation of set length.

Cone length (mtrs) = \( \frac{\text{Cone weight (lbs) } \times \text{Count } \times 840}{1.0936} \)

Cone length (mtrs) = \( \frac{4.167 \times 30 \times 840}{1.0936} = 96020.85 \ m \)

Set length = \( \frac{\text{Cone length } - \text{Cone remainder}}{\text{No of warper beams}} \times \text{No of creels} \)

Set length = \( \frac{96020-960}{8} \times 1 = 11885 \ m \)

Now calculating the number of bags required to warp the set of given quality

Number of bags = \( \frac{\text{Total ends} \times \text{Number of creels}}{\text{Number of beams} \times \text{Cones/bag}} \)

Number of bags = \( \frac{5915 \times 1}{8 \times 24} = 30.8073 \) bags

So, there will be 30 complete bags and some cones

Number of cones = 0.8073 \times 24 = 19.375 = 20 cones

So, the amount of yarn required to warp a set of single creel is 30 bags and 20 cones.

Set Calculation for 2 Creels:

Number of beams = 8

Since the number of beams (8) is divisible by number of creels (2), so we will proceed with same number of ends/beam and same number of beams.

Set length = \( \frac{\text{Cone length } - \text{Cone remainder}}{\text{No of warper beams}} \times \text{No of creels} \)

Set length = \( \frac{96020-960}{8} \times 2 = 23765 \) meters
Similarly, the number of bags are calculated as:

Number of bags = \( \frac{\text{Total ends} \times \text{Number of creels}}{\text{Number of beams} \times \text{cones/bag}} \)

Number of bags = \( \frac{5915 \times 2}{8 \times 24} = 61.615 \) bags

So, there will be 61 complete bags and some cones

Number of cones = 0.615 \times 24 = 14.75 = 15 cones

So, the amount of yarn required to warp a set of double creel is 61 bags and 15 cones.

**Set Calculation for 3 Creels:**

If number of creels is more than one, the number of beams should be a multiple of number of creels. This condition is not satisfied in this case, as the number of beams (8) is not divisible by number of creels (3). So the set will comprise of number of warper beams, multiple of number of creels, i.e.

Number of beams=9

No. of ends/warper beam = \( \frac{\text{Total ends}}{\text{No. of warper beams}} \)

No. of ends/warper beam = \( \frac{5915}{9} = 657.22 \)

Now, it can be 658 ends/beam or 657 ends/beam. To calculate it, take the figure after decimal point and multiply it with total number of beams.

No. of beams with one more end = 0.22 \times 9 = 2

So, two beams will be of 658 ends and 7 beams (9 – 2 = 7) will be of 657 ends. The total ends can be verified as:

657 \times 7 = 4599 ends

658 \times 2 = 1316 ends
Total ends = 5915

Next step is the calculation of length available on the cone of given weight and ultimately the calculation of set length.

\[
\text{Set length} = \frac{\text{Cone length} - \text{Cone remainder}}{\text{No. of warper beams}} \times \text{No. of creels}
\]

\[
\text{Set length} = \frac{96020 - 960}{9} \times 3 = 31685 \text{ meters}
\]

Similarly, the amount of yarn can be calculated as:

\[
\text{Number of bags} = \frac{\text{Total ends} \times \text{Number of creels}}{\text{Number of beams} \times \text{cones/bag}}
\]

\[
\text{Number of bags} = \frac{5915 \times 3}{9 \times 24} = 82.153 \text{ bags}
\]

So, there will be 82 complete bags and some cones

\[
\text{Number of cones} = 0.153 \times 24 = 3.667 = 4 \text{ cones}
\]

So, the amount of yarn required to warp a set of three creel is 82 bags and 4 cones.

**Set Calculation for 4 Creels:**

Number of beams = 8

Since number of beams (8) is divisible by number of creels (4), so we can proceed with same number of ends and same number of beams.

\[
\text{Set length} = \frac{\text{Cone length} - \text{Cone remainder}}{\text{No. of warper beams}} \times \text{No. of creels}
\]

\[
\text{Set length} = \frac{96020 - 960}{8} \times 4 = 47530 \text{ mtrs}
\]

The amount of yarn required is:
Number of bags = \( \frac{\text{Total ends} \times \text{Number of creels}}{\text{Number of beams} \times \text{cones/bag}} = \frac{5915 \times 4}{8 \times 24} = 123.229 \text{ bags} \)

Number of bags = \( \frac{5915 \times 4}{8 \times 24} = 123.229 \text{ bags} \)

So, there will be 123 complete bags and some cones

Number of cones = \( 0.229 \times 24 = 5.49 = 6 \text{ cones} \)

So, the amount of yarn required to warp a set of four creel is 123 bags and 6 cones.

**Example 3.2:**

*Calculate the Number of cones and weight of cone in grams to produce a warp set of 1500 meters of following quality to be run on 210cm loom with single weaver’s beam. Cone remainder is equal to 1000 meters and creel capacity is 672.*

**Solution:**

Quality: \( 20 \times 16 / 128 \times 60, 63” \)

No of widths = \( \frac{\text{Loom width}}{\text{Cloth width}} = \frac{82.67”}{63”} \approx 1 \text{ width} \)

Total ends in weaver’s beam = \( \frac{\text{Ends/inch} \times \text{Width} \times \text{No of widths}}{\text{No of weaver’s beam}} \)

Total ends in weaver’s beam = \( \frac{128 \times 63 \times 1}{1} = 8064 \text{ ends} \)

No of Warper beam = \( \frac{\text{Total ends}}{\text{Creel capacity}} = \frac{T.E}{C.C} \)

No of Warper beam = \( \frac{8064}{672} = 12 \)

No of ends/warper beam = \( \frac{\text{Total ends}}{\text{No of warper beams}} \)

No of ends/warper beam = \( \frac{8064}{12} = 672 \)

So, all the 12 beams will be of 672 ends, giving total ends of the set.

Total Ends = \( 672 \times 12 = 8064 \)

Number of cones = Number of ends/beam = 672

Next step is the calculation of cone length.
Set length = \( \frac{\text{Cone length} - \text{Cone remainder}}{\text{No of warper beams}} \times \text{No of creels} \)

\[
\text{Cone length} = \frac{\text{Set length} \times \text{No of warper beams}}{\text{No of creels}} + \text{Cone remainder}
\]

\[
\text{Cone length} = \frac{1500 \times 12}{1} + 1000 = 19000 \text{ meters}
\]

Using the cone length, calculate the cone weight.

\[
\text{Cone length (mtrs)} = \frac{\text{Cone weight(lbs)} \times \text{Count} \times 840}{1.0936}
\]

\[
\text{Cone weight (lbs)} = \frac{\text{Cone length(mtrs)} \times 1.0936}{\text{Count} \times 840}
\]

\[
\text{Cone weight (lbs)} = \frac{19000 \times 1.0936}{20 \times 840} = 1.2368 \text{ lbs}
\]

\[
\text{Cone weight (grams)} = 1.2368 \times 453.6 = 561 \text{ grams}
\]

### 3.1.2 Warp beam capacity

The term warp beam capacity is used to show the amount of yarn that can be warped on a certain warp beam. This information is important while planning the number of creels and beam length, relative to the cone length. Consider a warp beam as shown in the figure 3.1.

![Warper beam diagram](image)

**Figure 3.1 Warper beam**

Here, D is diameter of flange, d is diameter of barrel and L is distance between two flanges of the beam.
Area of cross section of barrel, \( A_1 = \pi r^2 = \frac{\pi}{4}d^2 \)

Area of cross section of Flange, \( A_2 = \frac{\pi}{4}D^2 \)

Area of cross section of empty beam, \( A = \frac{\pi}{4}(D^2 - d^2) \)

The volume of the empty warp beam can be calculated as:

\[
Volume, \ V = Area \ of \ cross \ section \times \ Space \ between \ two \ flanges
\]

\[
Volume, \ V = \frac{\pi}{4}(D^2 - d^2) \times L
\]

Using the relation of density and volume, mass can be calculated.

\[
Density = \frac{Mass \ (g)}{Volume \ (cm^3)}
\]

If, \( \rho = \text{density of beam} \)

\( M = \text{mass of yarn on beam} \)

Then, \( M \ (\text{grams}) = \rho \times \frac{\pi}{4}(D^2 - d^2) \times L \)

Mass of yarn on warp beam can be calculated as:

\[
\text{Mass of warp (lbs)} = \frac{\text{Length (yards)} \times \text{No. of ends}}{840 \times \text{Count}}
\]

\[
M \ (\text{grms}) = \frac{\text{Length (yards) } \times \text{Ends}}{840 \times \text{Count}} \times 453.6
\]

Comparing both the equations

\[
\frac{\text{Length (yards) } \times \text{Ends}}{840 \times \text{Count}} \times 453.6 = \rho \times \frac{\pi}{4}(D^2 - d^2) \times L
\]

\[
\text{Density, } \rho = \frac{\text{Length (yards) } \times \text{Ends}}{1.45 \times (D^2 - d^2) \times \text{LC}}
\]

\[
\text{Density, } \rho = \frac{\text{Length (meters) } \times \text{Ends}}{1.33 \times (D^2 - d^2) \times \text{LC}}
\]

So the density of a warp beam can be calculated if beam length, ends/warp beam, yarn count and dimensions of beam are known.
Example 3.3:

Determine the density of yarn on warp beam if warp count is 20/1 PC, length of warp sheet is 31650 meter and ends/beam are 672. The beam specifications are as follows:

Flange diameter, \( D = 1000 \text{ mm} = 100 \text{ cm} \)

Barrel diameter, \( d = 315 \text{ mm} = 31.5 \text{ cm} \)

Space between flanges, \( L = 2400 \text{ mm} = 240 \text{ cm} \)

Solution:

We know that the density of warp beam is calculated using the following relation:

\[
\rho = \frac{\text{Length (yards)} \times \text{Ends}}{1.33 \times (D^2 - d^2) \times \text{LC}}
\]

Density, \( \rho = \frac{31650 \times 672}{1.33 \times (100^2 - 31.5^2) \times 240 \times 20} \)

Density, \( \rho = 0.3698 \text{ gm/cm}^3 \)

3.1.3 Quality of warp yarn

The quality of warp yarn represents the imperfections in the yarn. It may be checked in two ways, weight method and length method.

In weight method quality of warp is checked in term of pounds per break (lbs/break). It can be checked by the given formula:

\[
\text{Lbs/break} = \frac{\text{Length} \times \text{Ends} \times 1.0936}{840 \times \text{Count} \times \text{Number of breaks}}
\]

Higher the lbs/ break of warp yarn better will be the quality of yarn.

The length of all the ends is calculated and the number of breaks per unit length determines the quality of warp.
In length method, the breaks per 10 million meter (Mm) are calculated as follow:

\[
\text{Breaks/10Mm} = \frac{\text{Number of breaks} \times 10^7}{\text{Length (meters)} \times \text{Ends}}
\]

**Example 3.4:**

*Express the quality of yarn used to warp the quality 30×30/91×86, 65” in terms of weight and length. Set length was 8500 meters and ends were 5915 in the set. The total number of breakages were 24.*

**Solution:**

In terms of weight the yarn quality is expressed as:

\[
\text{Lbs/break} = \frac{\text{Length} \times \text{Ends} \times 1.0936}{840 \times \text{Count} \times \text{Number of breaks}}
\]

\[
\text{Lbs/break} = \frac{8500 \times 5915 \times 1.0936}{840 \times 30 \times 24}
\]

Lbs/break = 90.91

In length method, the breaks per 10 mm are:

\[
\text{Breaks/10Mm} = \frac{\text{Number of breaks} \times 10^7}{\text{Length (meters)} \times \text{Ends}}
\]

\[
\text{Breaks/10Mm} = \frac{24 \times 10^7}{8500 \times 5915}
\]

Breaks/10Mm = 4.77

**3.1.4 Warping machine efficiency**

The efficiency of warping machine depends upon number of beams/creel, number of creels/set, yarn breakages, machine speed and size of the supply package. To calculate the efficiency of warping machine, a number of factors need to be considered. These factors include set length, machine speed, creel change time, comb filling time, number of beams/creel, beam change time, number of warp breaks and time to repair the break. To determine the efficiency, actual running time is calculated by excluding the total stoppage time from the total available time and then following relation is used to determine efficiency.
\[
\text{Efficiency (w.r.t. time)} = \frac{\text{Actual Running Time}}{\text{Total Available Time}} \times 100
\]

**Example 3.5:**

*Calculate the efficiency of warping machine for 30×20/145×76, 75”. The specifications are given:*

Set length = 23500 meters

Machine speed = 850 m/min

Creel change time = 20 min

Comb filling time = 25 min

No of beams/creel = 5

Beam change time = 5 min

Warp break/beam = 10

Time to repair break = 1.5 min

**Solution:**

\[
\text{Efficiency (w.r.t. time)} = \frac{\text{Actual Running Time}}{\text{Total Available Time}} \times 100
\]

Firstly, the actual running time can be calculated as:

\[
\text{Actual running time} = \frac{\text{Total length of warp (meters)}}{\text{Machine speed (m/min)}}
\]

\[
\text{Actual running time} = \frac{\text{Set length (meters) \times Beams/creel}}{\text{Machine speed (m/min)}}
\]

\[
\text{Actual running time} = \frac{23500 \times 5}{850} = 138.26 \text{ min}
\]

Total Stoppages:

Creel change = 20 min
Comb filling $= 25 \text{ min}$

Breakage repairing $= \text{Total breaks} \times \text{Time to repair one break}$

$= 10 \times 1.5 = 15 \text{ min}$

Beam change $= \text{Total beams} \times \text{Beam change time}$

$= 5 \times 5 = 25 \text{ min}$

Total stoppages $= 20 + 25 + 15 + 25 = 85 \text{ min}$

So,

$\text{Total available time} = \text{Actual running time} + \text{Total stoppages}$

$\text{Total available time} = 138.26 + 85 = 223.26 \text{ min}$

$\text{Efficiency}_{(w.r.t. \text{ time})} = \frac{\text{Actual Running Time}}{\text{Total Available Time}} \times 100$

$\text{Efficiency}_{(w.r.t. \text{ time})} = \frac{138.25}{223.26} \times 100 = 61.9 \%$

### 3.2 Sectional warping

It is also called as indirect warping, pattern warping, band warping or drum warping. It is suitable for all warp patterned fabrics e.g. stripes and checks. Sometimes this process is carried out for plied or synthetic warps where no sizing is needed. It is a two stage process, namely Warping and Beaming. Warping is done from creel to drum in the form of individual sections and beaming involves transfer of yarns from drum to beam in sheet form.

### 3.2.1 Sectional Warping Calculations

The sectional warping calculations are performed in the following steps.

**Step 1:** Determine creel capacity

The creel capacity to be used is determined based on the repeat size of stripe and number of repeats to be accommodated in one section. Additionally, the available creel capacity and the number of cones (for each color) must also be considered at this steps.

$\text{Creel Capacity} = n \times \text{Repeat size}$
Where “n” is any whole number integer.

Step 2: Determine the number of sections

Number of sections are calculated based on the total ends in the fabric and the creel capacity to be used

\[
\text{Number of sections} = \frac{\text{Total ends}}{\text{Creel capacity}}
\]

If number of sections is not a whole number like 18.35, then

\[
\text{Ends of cut-able section} = \text{Fraction} \times \text{Creel Capacity}
\]

Step 3: Determine the section width

The width of each section is calculated, based on the beam space available and the number of sections planned.

\[
\text{Section width (mm)} = \frac{\text{Beam Space (mm)}}{\text{Number of sections}}
\]

Step 4: Determine the section reed count

It is important to determine the section reed count, for controlling the section width as per our requirement. It is calculated as:

\[
\text{Reed Count (dents/inch)} = \frac{\text{Section Ends} \times 25.4}{\text{Section Width (mm)} \times \text{Reed denting}}
\]

Example 3.6:

Perform the sectional warping calculations for the following parameters. The warp repeat is on 164 ends, and beam space is 2400 mm, while the total ends of the quality are 6020.

Solution:

Section ends = n \times (warp repeat)

\[= 2 \times 164 = 328\]

No. of sections = Total ends / Section ends
= 6020 / 328
= 18.3536

Cut-able section ends = Fraction x Creel Capacity

= 0.3536 x 328 = 116

Means 18 sections will have 328 ends and 19th section will have 116 ends.

Section width = Beam space / No. of sections

= 2400 / 18.35 = 130.79 mm

Reed Count (dents/inch) = \( \frac{\text{Section Ends} \times 25.4}{\text{Section Width (mm)} \times \text{Reed denting}} \)

Reed Count (dents/inch) = \( \frac{328 \times 25.4}{130.79 \times 3} \)

Reed Count (dents/inch) = 21.23

We can also use split denting as:

Reed filling = \( \frac{\text{Ends per section}}{\text{Total dents used}} \)

= 328 / 130.79

= 2.5078 (actual)

Actual Reed Filling = 2.5078 x 2 = 5.015 (Suppose we take 2 dents)

Ends / dent Repeat = 5 ends/ 2 dents

Now it will be 3 ends/dent and 2 ends/dent alternately.

**Example 3.7:**

*A fabric having 5460 ends is to be warped on a sectional warping machine. There are three differently coloured yarns (white, black and red) in the fabric. The number of threads in a repeat are 96 (40 white, 40 black and 16 red). The number of cones available is 165, 167 and 50 for*
white, black and red color respectively. Perform the sectional warping calculations if beam space is 2000 mm and denting is 2. Also determine the beam length if yarn count is 30/s and cone weight is 1.50 lbs.

Solution:

The number of black and white colored cones is enough to produce 4 repeats, but the red colored cones can produce only three repeats in a section (due to limited number). Therefore, we can use 3 repeats in a section.

Section ends = n × (warp repeat)

= 3 × 96 = 288

No. of sections = Total ends / Section ends

= 5460 / 288

= 18.9583

Cut-able section ends = Fraction x Creel Capacity

= 0.9583 x 288 = 276

Means 18 sections will have 288 ends and 19th section will have 276 ends.

Section width = Beam space / No. of sections

= 2000 / 18.9583 = 105.49 mm

Reed Count (dents/inch) = \( \frac{\text{Section Ends} \times 25.4}{\text{Section Width (mm)} \times \text{Reed denting}} \)

Reed Count (dents/inch) = \( \frac{288 \times 25.4}{105.49 \times 2} \)

Reed Count (dents/inch) = 34.67

In case of non-availability of reed, the warping may be planned with reed denting of 2 or split denting may also be used.

Now to determine the beam length,
Cone length (m) = 30 \times 768.1 \times 1.5

Cone length (m) = 34564.5 m

If 97% of the cone length will be taken, then

Cone length taken (m) = 34564.5 \times 0.97

Cone length taken (m) = 33527.5

The beam length is now calculated as:

\[
\text{Beam length (m)} = \frac{\text{Cone length taken (m)}}{\text{Number of sections}}
\]

In the determination of beam length, the number of sections are considered in whole number only and are rounded up. Therefore, in this case the number of sections was 18.953 and will be rounded up to 19.

\[
\text{Beam length (m)} = \frac{33527.5}{19}
\]

Beam length = 1765 m approx.

### 3.2.2 Section Building on Section Warping

The section building while sectional warping depends on relation in between the rate of traverse, rate of increase in the section thickness and the angle of inclination.
In the Figure 3.2,

\( H = \) Height of the wedge or inclination

\( T = \) Distance of the edge of the swift from the starting point of First Section.

\( \theta = \) Angle of the inclination.

\( t = \) Traverse of reed

Suppose for a specific warp length the height (thickness) is “H”. So from triangle ABC the \( \tan \theta \) can be calculated as:

\[
\tan \theta = \frac{AB}{AC} = \frac{H}{T}
\]

\[
\frac{1}{\tan \theta} = \frac{T}{H}
\]

Similarly from triangle A’B’C

\[
\tan \theta = \frac{A'B'}{A'C} = \frac{h}{t}
\]

Comparing both,

\[
\frac{H}{T} = \frac{h}{t}
\]

\[
t = h \frac{T}{H} = \frac{h}{\tan \theta}
\]

This result shows that traverse speed is directly proportional to depth of section and inversely proportional to slope of cone.

**Example 3.6:**
A multicolor warp of 20-tex spun yarn is wound on the horizontal section swift of 1.5-meter diameter on which cones are fixed at 15° to drum axis. Each warp is 3000-meter long and the width of warp sheet on the swift is 2 meter. It contains 6500 ends while the density of yarn is 0.6 g/cm³. Calculate the depth of yarn and traverse per section.

**Solution:**

Dia of swift, \( d_1 = 1.5 \text{ m} = 150 \text{ cm} \)

Dia. of swift with yarn, \( d_2 =? \)

Width of yarn sheet on swift = 2 meter

Width of yarn sheet on swift = 200 cm

\[
\text{Tex Count} = \frac{\text{Weight (gms)}}{\text{Length (mtrs)}} \times 1000
\]

Length(mtrs) = Number of ends \( \times \) length/warp = 6500 \( \times \) 3000 m

\[
\text{Weight (gms)} = \frac{\text{Count} \times \text{Length (mtrs)}}{1000}
\]

\[
\text{Weight (gms)} = \frac{20 \times 6500 \times 3000}{1000}
\]

\[
\text{Weight (gms)} = 390,000 \text{ grams}
\]
Hence, the mass of yarn on swift is 390,000 grams.

\[
Volume \ of \ yarn = \frac{Mass}{Density}
\]

\[
Volume \ of \ yarn = \frac{390,000}{0.6}
\]

\[
Volume \ of \ yarn = 650,000 \ cm^3
\]

But

\[
Volume = \frac{\pi}{4} (d_2^2 - d_1^2) \cdot l
\]

\[
650,000 = \frac{3.1416}{4} (d_2^2 - 150^2) \times 200
\]

\[
d_2^2 - 150^2 = \frac{650,000 \times 4}{3.1416 \times 200}
\]

\[
d_2^2 = 150^2 + 4140
\]

\[
d_2^2 = 26640
\]

\[
d_2 = 163.2 \ cm
\]

Hence,

\[
2h = d_2 - d_1
\]

\[
2h = 163.2 - 150 = 13.2 \ cm
\]

\[
h = 13.2/2 = 6.66 \ cm
\]

Now, h is 6.66 cm, and angle is 15°

\[
t = \frac{h}{\tan \theta}
\]

\[
t = \frac{6.66}{\tan(15°)}
\]
3.3 Exercise

Problem 1: Calculate the no. of warper beams and set length that can be achieved with cone weight of 1.25 lbs. for given quality, if wastages are 2.5%. Also find the number of cones required.
Quality: $20 \times 20 / 88 \times 76, 75\"$

Problem 2: Calculate the cone weight in grams and number of warper beams required to produce a set length of 5000 meters for mentioned quality. Allow 900 meters length for wastages and remainders.
Quality: $10 \times 10 / 74 \times 44, 63\"$

Problem 3: Calculate the amount of yarn in lbs. required to achieve a set length of 4500 meters for the mentioned quality, while the length taken percentage is 97% of the cone length.
Quality: $30 \times 20 / 130 \times 80, 63\"$

Problem 4: Calculate the set length in meters that can be achieved from a single creel, with the individual cone weight of 4.167 lbs. The allowance for wastages and remainders accounts for 2%.
Quality: $30 \times 30 / 144 \times 74, 65\"$

Problem 5: Calculate the number of cones and total yarn weight required to produce a set of 8 warper beams. The set length required is 3000 meters and the wastages and remainders account for 5% of the cone length.
Quality: $80 \times 80 / 110 \times 80, 63\"$

Problem 6: Calculate the amount of yarn in bags, to warp a set of 8 warp beams. The length of warp on each beam is 24000 yards, and there are 562 ends in each beam. The wastages and remainders allowance is 1.5%.
Quality: $30 \times 30 / 124 \times 60, 72\"$
Problem 7: Calculate the set length in meters that can be achieved from a double creel, with the individual cone weight of 2.08 lbs. The allowance for wastages and remainders accounts for 1%.

Quality: 70 × 80 / 160 × 110, 72”

Problem 8: Calculate the cone weight in lbs. required to achieve a set length of 8000 yards for the below mentioned quality, while the length taken percentage is 97.5% of the cone length.

Quality: 60 × 60 / 245 × 135, 70”

Problem 9: Calculate the total yarn weight in bags required to produce a set length of 4500 meters, where the wastages and remainders account for 4% of the cone length.

Quality: 40 × 40 / 155 × 90, 63”

Problem 10: Calculate the running parameters for sectional warping, if the color repeat in warp is on 84 ends, the beam space is 2000 mm, while the total ends of the quality are 6300.

Problem 11: Perform sectional warping calculations, if the required stripe size (on loom) is 5 mm. The beam space is 2200 mm.

Quality: 20 × 20 / 60 × 60, 63”
4. Sizing

The weaving requires warp yarn to be strong, smooth and elastic to a certain degree. To achieve these properties, protective coating of a film forming agent (size material) is applied to the warp yarns prior to weaving. The application of size material on the warp sheet, to induce the desired properties is called slashing or sizing. Sizing is to produce “Quality Fabric” economically and efficiently.

The warp yarn is under three types of tensions during weaving on loom, namely: constant mean tension, cyclic tension variation and random tension variation. Constant mean tension is determined by the take up/let off rate and elasticity of warp yarn. Mean tension is usually not the cause for warp breakage. Cyclic tension variations are caused by shedding and beat up and depend on the fabric design and structure. As shown in figure, the highest peak tension is critical which may cause weak yarns to break. Random tension variations are caused by different reasons.
such as improper knots, entanglement of warp yarns due to protruding fibres, etc. a thick knot may not pass through heddle eye or reed easily. Sizing helps the warp sheet to bear these tensions.

The main objectives of sizing are as follows:

- To get the required number of ends on a weavers beam
- To increase the strength of yarn
- To cover the yarn hairiness and avoid fibres tangling
- To maintain flexibility in yarn
- To make yarn surface smooth and pliable

### 4.1 Warp tension zone calculations

The warp sheet is under a lot of tensions during sizing. It affects the elongation and stretch of yarn. Also the tension should be comparable with the tensile strength of the yarn, to avoid excessive breakages during sizing. There are six tension zones identified in a sizing machine as shown in Figure 4.1.

- **Zone 1** (Let off zone): From 1st warping beam of creel to drag roll at size box
- **Zone 2** (In-let zone): From drag roll to first nip
- **Zone 3** (Wet zone): From 2nd nip to first drying cylinder
- **Zone 4** (Dry section): From last drying cylinder to guide roll (headstock)
- **Zone 5** (Winding zone): From guide roll to weaver's beam
- **Zone 6** (Pressing zone): Tension by press trolley on the beam
The maximum tension a warp sheet can withstand depends on the linear weight of the warp sheet. It is different for each zone and can be determined by using the following relation:

\[
\text{Tension} = W_{\text{warp}} \times \text{Multiplication Factor}
\]

Where, the \( W_{\text{warp}} \) is the linear weight of warp sheet in terms of gram/meter and can be calculated by the relation:

\[
W_{\text{warp}} = \frac{\text{Total ends} \times 1.0936}{840 \times \text{Yarn count}} \times 453.6
\]

The multiplication factor for different zones is given below.

<table>
<thead>
<tr>
<th>Tension zone</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Let-off tension, ( F_L )</td>
<td>5 – 7</td>
</tr>
<tr>
<td>In-let tension, ( F_I )</td>
<td>3 – 4</td>
</tr>
<tr>
<td>Wet splitting tension, ( F_{WS} )</td>
<td>3.5</td>
</tr>
<tr>
<td>Dry tension, ( F_D )</td>
<td>14</td>
</tr>
<tr>
<td>Winding tension, ( F_W )</td>
<td>18 – 20</td>
</tr>
<tr>
<td>Pressing Tension, ( F_P )</td>
<td>16</td>
</tr>
</tbody>
</table>

**Example 4.1:**

*Calculate the warp sheet tension in different zones of sizing machine for the quality: 21 × 16 / 128 × 60, 63”*

**Solution:**

We know that the warp tension is dependent on the linear weight of the warp sheet.
\[ W_{\text{warp}} = \frac{\text{Total ends} \times 1.0936}{840 \times \text{Yarn count}} \times 453.6 \]

\[ W_{\text{warp}} = \frac{128 \times 63 \times 1.0936}{840 \times 21} \times 453.6 \]

\[ W_{\text{warp}} = 226.77 \text{ g/m} \]

Now, the tension of different zones is calculated as:

Let-off tension, \( F_L = 6 \times 226.77 = 1360.62 \)

In-let tension, \( F_I = 3 \times 226.77 = 680.31 \)

Wet splitting tension, \( F_{WS} = 3.5 \times 226.77 = 793.69 \)

Dry tension, \( F_D = 14 \times 226.77 = 3174.78 \)

Winding tension, \( F_W = 18 \times 226.77 = 4081.86 \)

Pressing Tension, \( F_P = 16 \times 226.77 = 3628.32 \)

4.2 Size liquor concentration

The size liquor concentration is defined as the amount of solid size contents expressed as %age of total volume of size liquor.

\[
\text{Size liquor conc.} \% = \frac{\text{Solid size contents (Kg)}}{\text{Volume of size liquor (Litres)}} \times 100
\]

4.3 Size add on

The size add on is the amount of size material stored on yarn, expressed as %age of its un-sized yarn weight.

\[
\text{Size add on} \% = \frac{\text{Weight of size material (Kg)}}{\text{Weight of unsized yarn (Kg)}} \times 100
\]

The weight of size material can be calculated as:

\[ \text{Weight of size material} = \text{Sized yarn weight} - \text{Un-sized warp weight} \]

The size take up is the mass of paste pick up in the size box (wet pick up) per unit weight of oven dry un-sized yarn prior to drying.
Size pick up = \( \frac{\text{Weight of size liquor (Liters)}}{\text{Weight of dry yarn (unsized) (Kg)}} \times 100 \)

### 4.4 Size box occupation

Size box occupation is also known as the cover factor of the size box. It is the space that a warp sheet occupies while being sized on the sizing machine, relative to the working width of the sizing machine. The size box occupation helps in determining the number of size boxes to be used during sizing process. Up to 65% size box occupation, a single size box is preferred, while for higher values double size box is used (double dip double nip). A cover factor of more than 65% will result in improper sizing of the sheet, resulting in poor performance on the loom. The size box occupation is determined by using the formula:

\[
\text{Size box occupation} \% = \frac{a}{b \times c} \times 100
\]

Where,

a = number of ends being run

b = yarns/unit length at 100%

c = distance between flanges of warp beam (width of warp sheet)

The size box occupation can also be calculated as:

\[
\text{Size box occupation} \% = \frac{\text{Actual yarns/unit length}}{\text{Yarns/unit length at 100\%}} \times 100
\]

**Example 4.2:**

Calculate the size box occupation of the quality 14 × 16 / 94 × 62, 63", if the working width of sizing machine is 1800 mm (same is the distance between the flanges of warp beam). The total number of ends in quality are 6000.

**Solution:**

The actual number of warp yarns per unit length are calculated as:

\[
\text{Actual yarns/unit length} = \frac{\text{Total ends}}{\text{Distance between flanges}}
\]

Actual yarns/unit length = 6000 / 1800 = 3.33 yarns/mm
The yarn diameter is calculated using the relation:

\[
Yarn\ Diameter\ (mm) = \frac{0.9071}{\sqrt{\text{Count}}}
\]

\[
Yarn\ Diameter\ (mm) = \frac{0.9071}{\sqrt{14}}
\]

Yarn diameter = 0.2424 mm

It means that 0.2424 mm area of the sizing machine working width is occupied by one yarn. Now, we need to calculate the number of yarns/unit length at 100%.

\[
Yarns/\text{unit length at 100\%} = \frac{1}{Yarn\ Diameter\ (mm)}
\]

\[
Yarns/\text{unit length at 100\%} = \frac{1}{0.2424}
\]

Yarns/unit length at 100% = 4.125 yarns/mm

Now, size box occupation is calculated as:

\[
\text{Size box occupation \%} = \frac{\text{Actual yarns/\text{unit length}}}{\text{Yarns/\text{unit length at 100\%}}} \times 100
\]

\[
\text{Size box occupation \%} = \frac{3.33}{4.125} \times 100
\]

Size box occupation = 80.73%

### 4.5 Sizing recipe calculation

Sizing recipe is the formulation that is used to cook or prepare a solution to apply on the warp sheet. This formulation is decided by careful considerations of yarn and process parameters. Some of the parameters are given in Figure 4.2.
Fig 4.2 Parameters affecting sizing quality

- Yarn Type: Staple, filament, ring, open end, comber, carded, etc.
- Material: cotton, viscose, polyester, etc.
- Quality: Hairiness, thick and thin places, etc.
- Sizing machine: pre wetting, cylinder or hot air drying, etc.
- Size recipe: Starch, PVA, CMC, etc.
- Size pick up: more or less, core sized, surface sized
- Loom Type: shuttle, air jet, rapier, etc.
- Weave: plain, twill, satin (warp tension varies with weave)
- Loom RPM: slow or high
- Personnel: trained properly or not
- Handling: machine speed, cylinder temp, etc.
- Adjustment: squeezing pressure, moisture, etc.

**Example 4.3:**

*Calculate the size recipe for a quality if the volume of size solution is 900 litres and concentration of this solution is 12%. The recipe being used is given below, along with solid contents:*
<table>
<thead>
<tr>
<th>Size Material</th>
<th>Quantity</th>
<th>Solid content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>50 kg</td>
<td>85 %</td>
</tr>
<tr>
<td>PVA</td>
<td>30 kg</td>
<td>96%</td>
</tr>
<tr>
<td>Acrylic</td>
<td>15 kg</td>
<td>85%</td>
</tr>
<tr>
<td>Wax</td>
<td>5 kg</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Solution:**

The size recipe concentration is calculated as:

\[
\text{Size recipe concentration} \% = \frac{\text{Solid contents (kg)}}{\text{Total volume (litres)}} \times 100
\]

\[
\text{Solid contents (kg)} = \frac{\text{Size recipe concentration} \times \text{Total volume (litres)}}{100}
\]

\[
\text{Solid contents} = \frac{(12 \times 900)}{100} = 108 \text{ kg}
\]

**4.6 Sizing cost**

Sizing cost is one of the most concerned aspects of weaving process. To maintain the cost effectiveness and stay in the competition, it is the utmost requirement of an industry to lower the cost of sizing. Being cost effective, the quality and efficiency of the subsequent processes should not suffer. That is why the sizing is rightly said to be the heart of weaving. The cost to size a warp sheet is expressed in terms of cost/kg or cost/meter.

**Example 4.4:**

*Calculate the sizing cost in terms of weight and length for the quality: 20 × 16 / 100 × 50, 69” (total ends=6900), to be sized in 6500 meters. The size recipe and cost of the chemicals is given below:*
<table>
<thead>
<tr>
<th>Size Material</th>
<th>Quantity</th>
<th>Unit Cost (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>100 kg</td>
<td>52</td>
</tr>
<tr>
<td>PVA</td>
<td>20 kg</td>
<td>270</td>
</tr>
<tr>
<td>Acrylic</td>
<td>15 kg</td>
<td>35</td>
</tr>
<tr>
<td>Wax</td>
<td>2 kg</td>
<td>350</td>
</tr>
</tbody>
</table>

Solution:

The total cost of recipe:

- Starch: $100 \times 52 = 5200$ Rs.
- PVA: $20 \times 270 = 5400$ Rs.
- Acrylic: $15 \times 35 = 525$ Rs.
- Wax: $2 \times 350 = 700$ Rs.

**Total cost = Rs. 11825/-**

Now the cost in terms of length can be calculated as:

\[
\text{Cost/meter (Rs.)} = \frac{\text{Total cost (Rs.)}}{\text{Warp sheet length (m)}}
\]

Cost/meter = $11825/6500 = 1.82$ Rs. (approx.)

To calculate the cost /kg, it is necessary to calculate the weight of warp sheet.

\[
\text{Weight of warp sheet (lbs)} = \frac{\text{Total ends} \times \text{Warp sheet length (m)}}{768.1 \times \text{Warp count}}
\]

\[
\text{Weight of warp sheet (lbs)} = \frac{6900 \times 6500}{768.1 \times 20}
\]
Weight of warp sheet = 2919.54 lbs

Weight of warp sheet = 2919.54/2.2046 = 1324.29 kg

Cost/kg (Rs.) = \(\frac{\text{Total cost}}{\text{Warp sheet weight (Kg)}}\)

Total cost/Warp Weight (kg) = 11825/1324.29 = 8.92 Rs. (approx.)

Example 4.5:

*Calculate the sizing cost per meter and kg for the quality: 21 × 21 / 108 × 56, 63”. The amount of yarn to be sized is 1500 kg, while the total recipe cost is Rs. 18500/-.*

**Solution:**

The cost in terms of weight can be calculated as:

\[
\text{Cost/kg (Rs.)} = \frac{\text{Total cost}}{\text{Warp sheet weight (Kg)}}
\]

Total cost/Warp Weight (kg) = 18500/1500 = 12.33 Rs. (approx.)

To calculate the cost /meter, it is necessary to calculate the length of 1500kg of warp sheet.

\[
\text{Weight of warp sheet (Kgs)} = \frac{\text{Total ends} \times \text{Warp sheet length (m)}}{768.1 \times \text{Warp count} \times 2.2046}
\]

\[
1500 = \frac{6804 \times \text{Warp sheet length (m)}}{768.1 \times 21 \times 2.2046}
\]

Warp sheet length = 7839.6 meter

Now the sizing cost in terms of length is:

\[
\text{Cost/meter (Rs.)} = \frac{18500}{7839.6}
\]

Cost/meter = 2.356 Rs. (approx.)
4.7 Yarn stretch

During sizing, the warp sheet is subjected to different kinds of tensions. As a result of these tensions, a stretch is produced in the warp sheet, which is known as the residual stretch. This stretch plays a significant role in the performance of yarn during the subsequent process of weaving. If the amount of stretch exceeds a nominal value, the threads become brittle leading to excessive breakages on loom. Therefore, it is important to check and control the stretches on warp sheet during sizing. The residual stretch is difference between the length of yarn fed and length of yarn delivered, expressed as percentage of warp length fed. It can be calculated by the formula:

$$\text{Residual stretch (\%)} = \frac{\text{Warp sheet delivered} - \text{Warp sheet fed}}{\text{Warp sheet fed}} \times 100$$

Where, the length of warp sheet delivered includes the sized length and the warp length wasted (both sized and unsized) during the process.

Example 4.6:

*Calculate the residual stretch in the warp sheet for the quality: 20 × 20 / 100 × 50, 63″. The length of warp sheet was 7500 meter, and three beams of 2500 meter each were sized. The total sized and unsized waste was 70 meters.*

**Solution:**

Length of warp sheet fed = 7500 meter

Total length of sized warp sheet = 3 × 2500 = 7500 meter

Warp sheet waste = 70 meter

Length of warp sheet delivered = 7500 + 70 = 7570 meter

$$\text{Residual stretch (\%)} = \frac{7570 - 7500}{7500} \times 100$$

Residual stretch (\%) = 0.93%

4.8 Size recipe calculations

Size recipe is the material that is cooked and applied to the yarn. The recipe is decided by careful consideration of yarn parameters including yarn count, strength, imperfections, hairiness, etc. Considering these parameters along with twist per inch helps in the preparation of a suitable recipe. A general ratio of recipe contents is given below.
Example 4.7:

Calculate the size recipe for a quality, if the total volume of size solution is 900 litres and concentration of the solution is 12%. The recipe being used is given below with solid contents %age.

**Solid contents:** Starch (85%), PVA (96%), Acrylic (85%), Softener (100%)

**Solution:**

The optimum ratio of these constituents has been discussed earlier. The concentration of size recipe is calculated as:

\[
\text{Size recipe concentration (\%)} = \frac{\text{Solid contents (Kg)}}{\text{Total volume (litres)}} \times 100
\]

It is given that the concentration of solution is 12%, and volume 900 litres. So, the solid contents in this volume can be calculated as:

\[
\text{Solid contents (Kg)} = \frac{\text{Concentration (\%)} \times \text{Total volume (litres)}}{100}
\]

Solid contents = \(\frac{12 \times 900}{100} = 108\) kg

Now, the solid contents of each ingredient will be calculated according to the specified ratio.

\[
\text{Solid contents of starch (Kg)} = \frac{50}{100} \times 108 = 54
\]

\[
\text{Solid contents of PVA (Kg)} = \frac{30}{100} \times 108 = 32.4
\]

\[
\text{Solid contents of acrylic (Kg)} = \frac{15}{100} \times 108 = 16.2
\]

\[
\text{Solid contents of softener (Kg)} = \frac{5}{100} \times 108 = 5.4
\]
Using the solid content % and amount, the actual weight of ingredients used for the recipe will be calculated as:

\[
\text{Weight of starch (Kg)} = \frac{54}{85} \times 100 = 63.6
\]

\[
\text{Weight of PVA (Kg)} = \frac{32.4}{96} \times 100 = 33.8
\]

\[
\text{Weight of acrylic (Kg)} = \frac{16.2}{85} \times 100 = 19.1
\]

\[
\text{Weight of softener (Kg)} = \frac{5.4}{100} \times 100 = 5.4
\]

So, the actual recipe is:

- Starch = 63.6 kg
- PVA = 33.8 kg
- Acrylic = 19.1 kg
- Softener = 5.4 kg

Total ingredients = 121.9 kg

So, the amount of water in the recipe is 900-121.9 = 778.1 litres. If we consider the steam condensate allowance of 12%, the actual amount of water used for the recipe preparation will be calculated as follows:

\[
\text{Steam condensate (litres)} = \frac{12}{100} \times 778.1 = 93.4
\]

So, the water added at the start is 778.1-93.4 = 684.7 litres

4.9 Weavers beam space

The weavers beam space is a critical parameter for smooth running of the loom. If the weavers beam space is not in accordance with the cloth width, it will lead to excessive warp breakages on the receiving side of loom. If the weavers beam space is less than the fabric width, the abrasion between yarns and beam flange will take place resulting in yarn break. The weavers beam space depends on the following factors:
1. Number of weavers beams
2. Width of cloth
3. Weft contraction
4. Number of cloth rolls
5. Space between weavers beams (if more than one)
6. Space between fabric rolls

The different possible cases for weavers beam space and fabric width are given below.

(A) Single weavers beam and single fabric width
In this case, the beam space is equal to the reed space, where reed space is calculated as:

\[
\text{Reed space} = \text{Cloth width} + \text{Fabric contraction}
\]

This case is most common in narrow width looms (for example 190 cm, 210 cm), where one weavers beam is used to produce a single cloth width

(B) Two weavers' beam and one fabric width
In this case, beam space is equal to reed space, as shown in Figure 4.3.

\[
Z_1 + Z_2 + X = B
\]

If \( Z = Z_1 = Z_2 \), then

\[
2Z + X = B
\]
\[ Z = \frac{B - X}{2} \]

Where, \( Z \) denotes beam space, \( B \) is reed space and \( X \) is the distance between two beams.

**(C) Single weavers beam and two cloth widths**

This arrangement is shown in Figure 4.3.

![Figure 4.3 Single weavers beam and two cloth widths](image)

In this case, Beam space = Reed space

\[ Z = B_1 + B_2 + \frac{d}{D} \]

If \( B = B_1 = B_2 \), then

\[ Z = 2B + \frac{d}{D} \]

Space between two fabric width in case of tuck-in fabric, \( D = 30 \text{ mm} \)

Distance between two flanges in case of leno selvedge, \( d = 10 \text{ mm} \)

**(D) Two weavers beam and four cloth widths**

The two weavers beam and four cloth widths configuration is shown in Figure 4.5. In this case, the beam space is equal to the reed space.

![Figure 4.5 Two weavers beam and four cloth widths](image)
Figure 4.5 Two weaver’s beam and four fabric widths configuration

\[ Z_1 + Z_2 + X = B_1 + B_2 + B_3 + B_4 + d_1 + d_2 + d_3 \]

If \( Z = Z_1 = Z_2, B = B_1 = B_2 = B_3 = B_4 \) and \( d = d_1 = d_2 = d_3 \), then

\[ 2Z + X = 4B + 3d \]

\[ Z = \frac{4B + 3d - X}{2} \]

**Example 4.8:**

*Calculate the weavers beam space in cm for the quality: 40 × 40 / 100 × 80, 47”, with a weft contraction of 6%. The fabric is to be produced on 153” loom with twin beams and tuck in selvedge. The flange to flange distance between two beams is 120 mm and D is 30 mm.*

**Solution:**

\[ D = 30 \text{ mm} = \frac{30}{25.4} = 1.18” \]

\[ X = 120 \text{ mm} = \frac{120}{25.4} = 4.72” \]

Now,

Reed space = Cloth width \( \times (1 + \text{Weft contraction %}) \)

Reed space = \( 47 \times (1 + 0.06) = 49.82” \)

Next step is to calculate the number of cloth widths that can be produced on the loom.

\[ \text{Number of cloth widths} = \frac{\text{Loom width}}{\text{Reed space} + D} \]
Number of cloth widths = 153 / (49.82 + 1.18) = 3

\[ Z = \frac{3B + 2D - X}{2} \]

\[ Z = \frac{3(49.82) + 2(1.18) - 4.72}{2} \]

\[ Z = 73.55" = 186.82 \text{ cm} \]

**4.10 Size solution requirement**

It may be defined as the amount of size material that is required to apply on a warp sheet. This is the number of recipe batches needed to size a specific length of warp sheet. The requirement is necessary to facilitate the sizing processing and avoiding machine stoppage due to recipe shortage. The excessive recipe will result in the wastage of material and affect the cost of sizing.

**Example 4.9:**

*Calculate the amount of size liquor required to size 10,000 meter warp of a quality: 40 x 40 / 100 x 80, 105". The pick-up %age is 120% and total ends of the quality are 10500.*

**Solution:**

The weight of warp sheet to be size is calculated as:

\[ \text{Warp sheet weight (Kg)} = \frac{\text{Length} \times \text{Total ends}}{\text{Count} \times 768.1 \times 2.2046} \]

\[ \text{Warp sheet weight (Kg)} = \frac{10000 \times 10500}{40 \times 768.1 \times 2.2046} \]

Warp sheet weight = 1550.2 kg

The pick-up % is the amount of size solution paste on warp sheet in the wet form.

100 Kg of yarn require liquor = 120 litres

1 Kg of yarn require liquor = 120/100 = 1.2 litres

1550.2 Kg of yarn will require liquor = 1.2 \times 1550.2 = 1860 litres (approximately)
4.11  Steam requirement

Steam plays an important role in sizing process. Sizing is the heart of weaving and it breaths with steam. Variations in steam pressure or conditions seriously affect the quality of the sized yarn.

Steam is basically water in gas phase. When water is boiled at high temperatures it gets the form of steam. The volume of the water increases multiple times on heating and forms steam. Boilers are used in textile industry to generate steam at required temperature and pressure. Wood and coal based boilers are mostly used now a day.

Steam is used in sizing process at different stages. It is used to cook the size recipe in sizing cooker. At this stage direct heating is applied which decreases the viscosity of size solution because of steam condensate. Then steam is applied in storage tank to maintain the temperature of the size solution to a specific level. After that steam is applied to size box (for direct and indirect heating of size solution) on sizing machine.

Drying of sized yarn is done via drying cylinders in conventional sizing. So to maintain the temperature of the drying cylinder steam is required. Steam is applied to mini drying cylinders and the main drying cylinders. The applied steam to these cylinders converted to condensate water when wet yarn passes by these cylinders. So syphon system is applied to cylinders to extract water from the cylinders. This condensate will affect the drying process of yarn if not removed from the cylinders.

4.12  Size Solution Dosage

Size recipe is prepared in a size cooker and then transferred to the mother tank which is also known as storage tank or feed tank. This mother tank feeds size solution to the size box as per requirement of the process. The mother tank as well as size box is provided with the steam to avoid solidification or gelation of the size material. The size box comprises of a size tray and size box storage. One side of the size tray is adjustable to maintain required level of size solution in size tray. This level depends upon the yarn count and yarn type to be sized and the size pick up requirement. The size solution is continuously circulated from size box storage to size tray with the help of a pump. This circulation is necessary to maintain the uniformity of the size solution in terms of solid contents and to avoid gelation.

Size box storage is equipped with a pressure transducer that measures the level of size solution in size box storage. The size level to be maintained is fed at the control panel. When amount of size solution falls below this level, a signal is generated by pressure transducer and more size solution is released from mother tank to size box. In this way, level in size box is continuously maintained according to the usage of size solution for warp sheet. The schematic is shown in Fig 4.3. The size solution requirement or dosage is calculated according to the extent of sizing and warp sheet length to be sized.
The amount of size liquor in the size box is calculated as:

Amount of size liquor in size box (litres) = length (dm) × width (dm) × height of liquor (dm)

Now, the upper and lower limit of size liquor in the size box are calculated for the maximum and minimum height of size liquor in the size box.

Fig 4.3 Schematic of size solution dosage to the size box
Example 4.10:

Calculate the amount of size liquor to be fed in the size box, if the minimum, maximum and current level of size liquor is 40 cm, 75 cm and 50 cm respectively. The length and width of size box are 160 and 70 cm respectively.

Solution:

Minimum amount of liquor in size box = \((160/10) \times (70/10) \times (40/10)\)

Minimum amount of liquor in size box = 448 litres

Maximum amount of liquor in size box = \((160/10) \times (70/10) \times (70/10)\)

Maximum amount of liquor in size box = 784 litres

Current amount of liquor in size box = \((160/10) \times (70/10) \times (50/10)\)

Current amount of liquor in size box = 560 litres

Now, the amount of size liquor to be fed to the size box is calculated as:

Amount of liquor to be fed in size box = Maximum amount - Current amount

Amount of liquor to be fed in size box = 784 – 560 = 224 litres

4.13  Exercise

Problem 1: Calculate the cost/kg and cost/meter of the quality 80 × 80 / 240 × 160, 116”. The total warp sheet to be sized is 15000 yards, while recipe cost is Rs. 63215/-. 

Problem 2: For a particular quality, the warp sheet of 10500 meters is to be sized. Four sized beams of 2000 meter each and one sized beam of 2300 meter were produced. 250 meters unsized warp sheet was left on the beams while sized waste was 60 meters. Calculate the residual stretch % in the sized warp sheet.

Problem 3: Calculate the warp sheet tension in different zones of sizing machine for the quality: 40 × 40 / 120 × 110, 63”
Problem 4: Calculate the size box occupation of the quality 21 × 16 / 130 × 76, 63”, if the working width of sizing machine is 2400 mm (same is the distance between the flanges of warp beam). The total number of ends in quality are 8200.

Problem 5: Calculate the size recipe for a quality if the volume of size solution is 800 litres and concentration of this solution is 14%. The recipe being used is given below, along with solid contents:

<table>
<thead>
<tr>
<th>Size Material</th>
<th>Quantity</th>
<th>Solid content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>70 kg</td>
<td>85 %</td>
</tr>
<tr>
<td>PVA</td>
<td>25 kg</td>
<td>96%</td>
</tr>
<tr>
<td>Acrylic</td>
<td>10 kg</td>
<td>85%</td>
</tr>
<tr>
<td>Wax</td>
<td>5 kg</td>
<td>100%</td>
</tr>
</tbody>
</table>

Problem 6: Calculate the sizing cost in terms of weight and length for the quality: 30 × 20 / 130 × 69, 63” (total ends=8200), to be sized in 5000 meters. The size recipe and cost of the chemicals is given below:

<table>
<thead>
<tr>
<th>Size Material</th>
<th>Quantity</th>
<th>Unit Cost (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>120 kg</td>
<td>52</td>
</tr>
<tr>
<td>PVA</td>
<td>25 kg</td>
<td>270</td>
</tr>
<tr>
<td>Acrylic</td>
<td>20 kg</td>
<td>35</td>
</tr>
<tr>
<td>Wax</td>
<td>5 kg</td>
<td>350</td>
</tr>
</tbody>
</table>

Problem 7: Calculate the sizing cost per meter and kg for the quality: 60 × 60 / 106 × 96, 63”. The amount of yarn to be sized is 2000 kg, while the total recipe cost is Rs. 22500/-.
Problem 8: Calculate the residual stretch in the warp sheet for the quality: $24 \times 24 / 100 \times 50, 63''$. The length of warp sheet was 8400 meter, and four beams of 2100 meter each were sized. The total sized and unsized waste was 90 meters.

Problem 9: Calculate the size recipe for a quality, if the total volume of size solution is 900 litres and concentration of the solution is 8%. The recipe being used is given below with solid contents %age.

<table>
<thead>
<tr>
<th>Size Material</th>
<th>Quantity</th>
<th>Solid content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>60 kg</td>
<td>85 %</td>
</tr>
<tr>
<td>PVA</td>
<td>15 kg</td>
<td>96%</td>
</tr>
<tr>
<td>Acrylic</td>
<td>6 kg</td>
<td>85%</td>
</tr>
<tr>
<td>Acrylic</td>
<td>20 kg</td>
<td>35%</td>
</tr>
<tr>
<td>Wax</td>
<td>3 kg</td>
<td>100%</td>
</tr>
</tbody>
</table>

Problem 10: Calculate the weavers beam space in cm for the quality: $30 \times 20 / 96 \times 68, 45''$, with a weft contraction of 4%. The fabric is to be produced on 153” loom with twin beams and tuck in selvedge. The flange to flange distance between two beams is 120 mm and D is 30 mm.

Problem 11: Calculate the amount of size liquor required to size 50,000 meter warp of a quality: $20 \times 20 / 100 \times 50, 65''$. The pick-up %age is 125% and total ends of the quality are 6500.
CLOTH CALCULATIONS
Muhammad Imran Khan, Yasir Nawab

5. Cloth
The fabric produced as a result of weaving has a number of distinguishing parameters like yarn count, thread density, weave design, etc. These parameters have effect on the fabric properties as well as its costing. Also it is necessary to have information about the quantity of material required for the production of a specific quantity of fabric. The following calculations will help the readers to perform the material calculations and costing of the woven fabric.

5.1 Warp and weft calculations
A look at the fabric cross sectional view clarifies that the yarns are not laid straight in the fabric. Instead they tend to follow a wavy path, owing to the interlacement between yarns. These undulations cause the length of yarn to contract in the fabric, producing crimp. Apart from being essential in determining the quantities of yarn to be ordered for the production of a given cloth, the crimp determines many cloth characteristics such as tensile strength, rigidity, air permeability, etc.
5.1.1 Contraction%

The contraction is defined as the difference between the on loom and off loom width/length of fabric. The contraction depends on a number of factors including cloth parameters and loom settings. The cloth parameters determining the contraction include warp and weft count, ends/inch, picks/inch and the weave design. Plain weave has the maximum contraction (due to more intersection). Contraction is directly related to density and it also depends upon loom type and fibre. Some looms have reinforced backrest so they will apply more tension to yarn and hence more contraction. The following relations are used to determine the contraction:

\[
\text{Warp Contraction} = \frac{n_2 \times 3}{W.F. \times N_2}
\]

\[
\text{Weft Contraction} = \frac{N_1 + N_2}{\sqrt{n_1 + n_2}} + 1
\]

Where,

\[N_1 = \text{Warp count}\]

\[N_2 = \text{Weft count}\]

\[n_1 = \text{ends/inch}\]

\[n_2 = \text{picks/inch}\]

\[W.F. = \text{Weave factor}\]

The weave factor of a particular weave depends on the repeat size and the interlacement pattern of the yarns. The following relations are used to calculate the weave factor for any weave.

\[
K_c = \left(\frac{28 \times R}{R + (0.732 \times I)}\right)
\]

Where,

\[R = \text{Number of threads/weave repeat}\]

\[I = \text{Number of intersection/weave repeat}\]
The cross sections of 1/1 plain, 3/1 twill and 4/1 satin weave are shown in Figure 5.1. From the cross section of plain weave, it can be noted that the number of threads/repeat are 2, while number of intersections/weave are also 2.

\[
K_c = \left( \frac{28 \times 2}{2 + (0.732 \times 2)} \right)
\]

\[K_c = 16.17\]

Figure 5.1. Cross sections of 1/1 plain, 3/1 twill and 4/1 satin weave
In case of a 3/1 twill weave, there are 4 threads/repeat while number of intersections are 2/repeat. Hence, the value of $Kc$ can be calculated as:

\[ Kc = \left( \frac{28 \times 4}{4 + (0.732 \times 2)} \right) \]

\[ Kc = 20.498 \]

The weave factor is the ratio of $Kc$ of a particular weave to that of the plain fabric.

\[ \text{Weave factor (weave)} = \frac{Kc_{\text{weave}}}{Kc_{1/1}} \]

For example, the weave factor of 3/1 twill will be:

\[ \text{Weave factor (3/1)} = \frac{20.498}{16.17} \]

\[ \text{Weave factor (3/1)} = 1.26 \]

The weave factors for some basic weave designs are given below:

For 1/1 = 1

For 2/1 = 1.16

For 3/1 = 1.26

For 4/1 = 1.34

**Example 5.1:**

**Determine the warp and weft contractions for the given quality.**

**Quality: 30 × 30 / 76 × 68, 98” 2/1 twill**

**Solution:**

Here,

\[ N_1 = 30 \]

\[ N_2 = 30 \]
\( n_1 = 76 \)
\( n_2 = 68 \)
\( W.F. = 1.16 \)

\[
Warp\ Contraction = \frac{68 \times 3}{1.16 \times 30}
\]

Warp contraction = 5.86%

\[
Weft\ Contraction = \frac{30 + 30}{\sqrt{76 + 68}} + 1
\]

Weft contraction = 5.17%

### 5.1.2 Material requirement

It is important to have the knowledge of the material amount required for a particular order. It helps in the smooth running of process and timely completion of order. The material requirement is separately calculated for the warp and the weft, using the following relations:

\[
Warp\ yarn\ required\ (lbs.) = \frac{Tape\ length\ (yards) \times T.E}{840 \times Ne(warp)}
\]

\[
Weft\ yarn\ required\ (lbs) = \frac{(RS + 1.2) \times PPI \times CL\ (yards)}{840 \times Ne\ (weft)}
\]

\[
Tape\ length\ (yards) = \frac{Cloth\ length(yards) \times (100 + C_w\%)}{100}
\]

Where,

- CL = cloth length
- RS = reed space
- \( C_w \) = warp contraction %
- \( W_C \) = width of cloth
The reed width, RW can be calculated as:

\[ RS = W_c \times \frac{100 + C_f \%}{100} \]

Where, \( C_f \) is the filling contraction \%. It is also used to determine the contraction ends/inch.

\[ Contraction \ EPI = \frac{EPI \times C_f \%}{100} \]

The reed count may be calculated as:

\[ Reed \ count = \frac{EPI - Contraction \ EPI}{EPI} \]

The total ends (TE) for a particular quality are calculated using the below relation:

\[ Total \ ends = (Reed \ count \times Reed \ space \times Denting) + Selvedge \ ends \]

Where, Reed count is expressed in dents/inch, Reed space in inches and denting is the number of threads per dent. The extra selvedge ends are added to the total ends if the denting in selvedge portion is heavy as compared to the body of fabric.

**Example 5.2:**

*Determine the amount of material required to produce 4000 meter of the following quality. Where, warp and weft contractions are 8% and 3.5% respectively.*

**Quality:** 40×40/120×70, 112" 1/1 Plain

**Solution:**

\[ Reed \ count = \frac{EPI - (EPI \times C_f \%)}{Ends/dent} \]

\[ Reed \ count = \frac{120 - (120 \times 3.5\%)}{3} \]

Reed count = 38.6 dents/inch

\[ Reed \ space = Cloth \ width + (cloth \ width \times C_f \%) \]

Reed space = 112 \times (1+0.035) = 115.92"
Tape length = 1.0936 × (1+8%) = 1.181 yards

Total ends = Reed space × Reed count × Denting

Total ends = 115.92 × 38.6 × 3 = 13423

Now, the warp and weft weight required per yard are calculated as:

\[
Warp \ weight \ (lbs/yard) = \frac{Tape \ length \times TE}{840 \times Warp \ count}
\]

\[
Warp \ weight \ (lbs/yard) = \frac{1.181 \times 13423}{840 \times 40} = 0.471 \ lbs
\]

\[
Weft \ weight \ (lbs/yard) = \frac{(Reed \ space + wastage) \times PPI \times 1.0936}{840 \times Weft \ count}
\]

\[
Weft \ weight \ (lbs/yard) = \frac{(115.92 + 1.2) \times 70 \times 1.0936}{840 \times 40} = 0.2668 \ lbs
\]

Total weight (lbs/yard) = Warp weight + Weft weight

Total weight (lbs/yard) = 0.471 + 0.2668 = 0.7378 lbs

Total weight (lbs/meter) = 0.7378/0.9144=0.8068 lbs

For 4000 meter, the amount of material required is:

Material required = 4000×0.8068 = 3227.43 lbs

Number of bags = 3227.43/100 = 32.27 bags

Number of bags = 33 approx.

5.2 Fabric areal density

The fabric areal density is an important characteristic of fabric determining its performance. It depends on the fabric structural parameters like warp and weft linear density, thread density and their contractions (produced due to the interlacement of the yarns). The areal density is expressed in two ways: fabric weight per unit area and fabric weight per unit length. The fabric weight per unit area is expressed as grams/meter square (GSM).
\[ GSM \text{ (warp)} = \frac{epc \times Tex}{10} \times \left( \frac{100 + C_w \%}{100} \right) \]

\[ GSM \text{ (weft)} = \frac{ppc \times Tex}{10} \times \left( \frac{100 + C_f \%}{100} \right) \]

Where,

epc = ends per centimetre

ppc = picks per centimetre

Cw\% and Cf\% = Contraction percentage (warp & weft respectively)

Fabric GSM (without size) = GSM (warp) + GSM (weft)

This relation gives the GSM of fabric without taking into consideration the effect of size add on. The GSM of sized fabric can be calculated as:

\[ GSM \text{ (warp with size)} = GSM \text{ (without size)} \times \left( \frac{100 + S\%}{100} \right) \]

Where, S\% is the size percentage.

Fabric GSM (sized) = GSM (warp with size) + GSM (weft)

The other way to express areal density is the weight per unit length, i.e. grams per linear meter, also termed as fabric GLM.

\[ Fabric \text{ GLM} = \frac{Fabric \text{ GSM} \times \text{Width of cloth}}{39.37} \]

The same relation can also be used to determine the GLM of the components, i.e. warp and weft. The fabric GLM will then be the sum of both the components.

Fabric GLM = GLM (warp) + GLM (weft)

5.2.1 Derivation of the relation

By the definition of count, we know that it is the number of hanks per unit weight of the yarn.

\[ Ne = \frac{L \text{ (yards)}}{840 \times W \text{ (lbs)}} \]
\[
W(\text{gram}) = \frac{L(\text{yards}) \times 453.6}{840 \times Ne}
\]

\[
W(\text{gram}) = \frac{L(\text{inch}) \times 453.6}{840 \times Ne \times 36}
\]

\[
W(\text{gram/m}^2) = \frac{L(\text{inch}) \times 453.6 \times 39.37 \times 39.37}{840 \times Ne \times 36}
\]

\[
W(\text{gram/m}^2) = \frac{L(\text{inch}) \times 23.25}{Ne}
\]

Now, in this equation, the length in inches can be replaced with the EPI/PPI, if we are calculating for warp/weft. Also adding the effect of undulations produced in the yarn, the relation becomes:

\[
GSM(\text{warp}) = \frac{23.25 \times EPI}{\text{count of warp}} \times \frac{100 + C_w \%}{100}
\]

\[
GSM(\text{weft}) = \frac{23.25 \times PPI}{\text{count of weft}} \times \frac{100 + C_f \%}{100}
\]

Another relation used to get an approximate value of GSM is based on the cover factor of the fabric. According to this formula:

\[
GSM = \frac{24.9 \times Kc^2}{n_1 + n_2}
\]

\[
Kc = \frac{n_1}{\sqrt{N_1}} + \frac{n_2}{\sqrt{N_2}}
\]

Where, Kc is cover factor, N1 is warp count, N2 is weft count, n1 is EPI and n2 is PPI.

Example 5.3:

*Calculate the GSM and GLM with size for fabric quality 20×20/100×60, 63". The warp and weft contractions were 6.5% and 4.5% respectively. Take size add on in warp is 8.5%.*

Solution:

The following equations are used to determine the GSM.

Warp/Weft tex = 590.5/20 = 29.525
epc = 100/2.54 = 39.37

ppc = 60/2.54 = 23.62

\[
GSM\ (\text{warp}) = \frac{epc \times T_{ex}}{10} \times \left(\frac{100 + C_w\%}{100}\right) \times \left(\frac{100 + S\%}{100}\right) \\
GSM\ (\text{warp}) = \frac{39.37 \times 23.62}{10} \times \left(\frac{100 + 6.5\%}{100}\right) \times \left(\frac{100 + 8.5\%}{100}\right) \
\]

GSM (warp) = 106.96 gram

\[
GSM\ (\text{weft}) = \frac{ppc \times T_{ex}}{10} \times \left(\frac{100 + C_f\%}{100}\right) \\
GSM\ (\text{weft}) = \frac{23.62 \times 29.525}{10} \times \left(\frac{100 + 4.5\%}{100}\right) \
\]

GSM (weft) = 72.88 gram

GSM (cloth) = GSM (warp) + GSM (weft)

GSM (cloth) = 106.96 + 72.88 = 179.84 gram

\[
Fabric\ GLM = \frac{Fabric\ GSM \times Width\ of\ cloth}{39.37} \\
Fabric\ GLM = \frac{179.84 \times 63}{39.37} = 287.78\ gram
\]

5.3 Cost of production

Calculating production cost is an intricate process, involving a number of factors to be taken into consideration. The major contributing factors are the raw material cost and the conversion cost.

5.3.1 Raw material cost

The raw material for woven fabric is the yarn, used as either warp or weft. Therefore, the raw material cost is the material cost that will be consumed in the production of a certain quantity of fabric. Hence, it is necessary to calculate the amount of yarn required for determining the raw material cost. These calculations have been discussed earlier in detail in section 5.1.2, and the amount of material required may be calculated using the relations mentioned there.
Example 5.4:

For the below mentioned quality, determine the material cost. Where, warp and weft contractions are 9% and 3% respectively.

Quality: 40×40/100×80, 105” 1/1 Plain

Solution:

\[
Reed \ count = \frac{EPI - (EPI \times Cf\%)}{E/\text{dent}}
\]

\[
Reed \ count = \frac{100 - (100 \times 3\%)}{2}
\]

Reed count = 48.5 dents/inch

\[
Reed \ space = Cloth \ width + (cloth \ width \times Cf\%)
\]

Reed space = 105 × (1+0.03) = 108.15”

Tape length = 1.0936 × (1+9%) = 1.192 yards

To determine the total ends, it is necessary to have the information about the body reed space and the selvedge reed space. Let, if body reed space and the selvedge reed spaces are 106.93 and 1.2154 inches respectively, then total ends are:

Total ends = Body ends + Selvedge ends

Body ends = Body reed space × Reed count × Denting

Body ends = 106.93 × 48.5 × 2 = 10372

Selvedge ends = Selvedge reed space × Reed count × Denting

Body ends = 1.2154 × 48.5 × 3 = 176.84

Total ends = 10372 + 176.84 = 10548.84 = 10550 approx.

\[
Warp \ weight \ (lbs/yard) = \frac{\text{Tape length} \times TE}{840 \times \text{Warp count}}
\]

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\[ \text{Warp weight (lbs/yard)} = \frac{1.192 \times 10550}{840 \times 40} = 0.374 \text{ lbs} \]

\[ \text{Weft weight (lbs/yard)} = \frac{(Reed \ space + \ wastage) \times PPI \times 1.0936}{840 \times \text{Weft count}} \]

\[ \text{Weft weight (lbs/yard)} = \frac{(108.15 + 1.2) \times 80 \times 1.0936}{840 \times 40} = 0.2847 \text{ lbs} \]

Total weight (lbs/yard) = Warp weight + Weft weight

Total weight (lbs/yard) = 0.374 + 0.2847 = 0.6587 lbs

The yarn rate in the market for a 40/s yarn is Rs. 150/lbs. Therefore, the raw material cost per yard may be calculated as:

\[ \text{Raw material cost} = \text{Yarn weight} \times \text{Yarn rate} \]

\[ \text{Raw material cost} = 0.6587 \times 150 \]

\[ \text{Raw material cost} = 98.80 \text{ Rs. / yard} \]

5.3.2 Conversion cost

This is the cost incurred in converting the material from the yarn into the fabric form. It is the sum of total process cost, indirect material cost, administrative costs and FOH. In weaving process, the conversion of material from one to the other form takes place at a number of steps namely:

- Winding (pirn winding)
- Warping
- Sizing (steam cost)
- Drawing in
- Knotting
- On loom production
- Inspection and Packing

The sum of expenses incurred during these processes may be termed as the total process cost. It also involves the labour cost (direct and indirect) and electric cost (including AC, chiller, compressor) incurred during these processes.

The indirect material cost involves store expenditures including:
The factory overheads (FOH) generally applies to the indirect labor and indirect cost, including all costs involved in manufacturing with the exception of the cost of raw materials and direct labor. FOH in general includes:

- Quality assurance cost
- Clean up cost
- Property insurance cost
- Interests
- Depreciation
- Power and fuel
- Rents

Conversion cost can be calculated for certain period of time by considering all of above costs and number of picks inserted to produce fabric in that particular period. The general relation used to calculate the conversion cost is:

$$Conversion\ cost = \frac{Total\ cost\ during\ a\ time\ period}{Total\ picks\ inserted}$$

The one-month conversion costs for an organization are given below. It is obvious from the data that major portion of conversion cost is due to the process cost accounting for 88% approximately. The administrative expenses find a share of 4.9%, while indirect material cost and FOH have a share of 3.6% and 3.5% respectively.

**Table 5.1 Conversion cost (one month) break up for a textile mill**

<table>
<thead>
<tr>
<th>Expenditure head</th>
<th>Amount (Rs.)</th>
<th>Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total process cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sizing cost</td>
<td>5500000</td>
<td>19.4%</td>
</tr>
<tr>
<td>Electric cost</td>
<td>12000000</td>
<td>42.3%</td>
</tr>
<tr>
<td>Steam cost</td>
<td>800000</td>
<td>2.8%</td>
</tr>
<tr>
<td>Inspection and packing</td>
<td>1200000</td>
<td>4.2%</td>
</tr>
<tr>
<td>Labor cost</td>
<td>5500000</td>
<td>19.4%</td>
</tr>
<tr>
<td><strong>Indirect material cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Store cost</td>
<td>700000</td>
<td>2.5%</td>
</tr>
<tr>
<td>Repair</td>
<td>300000</td>
<td>1.1%</td>
</tr>
</tbody>
</table>
Winding cost

In fabric manufacturing, the remainders are left as baby cones during warping and weaving shed. These baby cones are rewind to produce a big package, suitable for next processes. The rewinding cost may be calculated using the following information.

Drum RPM = 2200
Drum diameter = 96 mm
Number of spindles = 48

Production of winding machine (if yarn count is 30 at 85% efficiency) can be calculated as discussed in chapter 2.

Production of 48 spindles/day = 1691.72 lbs

Monthly production = 50751.71 lbs

The total costs incurred in that machine during the month are as follows:

Salary of labour = 75,000 Rs.
Maintenance cost = 5,000 Rs.
Electrical cost = 54,000 Rs.
Factory overheads = 12,000 Rs.
Packing cost = 30,000 Rs.
Total cost = 176,000 Rs.

Now, the rewinding cost is calculated as:

\[
\text{Rewinding cost} = \frac{\text{Total cost}}{\text{Total production}}
\]

\[
\text{Rewinding cost} = \frac{176000}{50751.71}
\]
Rewinding cost = 3.467 Rs./lbs

Warping cost

The warping production can be calculated using relations mentioned in chapter 3, for given parameters.

Warping speed = 800 yards/min
Average ends/beam = 720
Yarn count = 30/1
Efficiency = 40%

Calculated warping production/day is 23040 lbs. If the costs incurred in a day are:

Salary of labour = 15,340 Rs.
Maintenance cost = 3,000 Rs.
Electrical cost = 15,000 Rs.
Factory overheads = 4,000 Rs.
Total cost = 37,340 Rs.

Now, the warping cost can be calculated as:

\[
Warping\ cost = \frac{Total\ cost}{Total\ production}
\]

\[
Warping\ cost = \frac{37340}{23040}
\]

Warping cost = 1.621 Rs./lbs

Sizing cost
To determine the sizing cost, the sizing production is first calculated using relations mentioned in chapter 4, for known parameters.

Sizing speed = 100 yards/min
Average total ends = 8000
Yarn count = 30/1
Efficiency = 50%

Calculated sizing production/day is 22857 lbs. If the costs incurred in a day are:

Salary of labour = 15,900 Rs.
Maintenance cost = 5,000 Rs.
Electrical cost = 22,000 Rs.
Factory overheads = 4,500 Rs.
Steam cost = 40,000 Rs.
Material cost = 200,000 Rs.
Total cost = 287,400 Rs.

Now, the sizing cost can be calculated as:

\[
\text{Sizing cost} = \frac{\text{Total cost}}{\text{Total production}}
\]

\[
\text{Sizing cost} = \frac{287400}{22857}
\]

Sizing cost = 12.57 Rs./lbs

**Rejection cost**

Rejection during one month = 2000 meter
If average cost per meter is 210 Rs., then total rejection cost is $2000 \times 210 = 420,000$.

\[
Rejection\ cost\ per\ meter = \frac{Total\ cost}{Total\ production}
\]

\[
Rejection\ cost\ per\ meter = \frac{420000}{12000000}
\]

Rejection cost/meter = 0.35 Rs./meter

**Example 5.5:**

*Calculate the conversion cost for the following quality, in context of the problem 5.4.*

**Quality:** $40\times40/100\times80$, 105” 1/1 Plain

**Solution:**

Total production = 1417780 m

Average picks/inch = 64.55

Total picks inserted = $1417780 \times 64.55 = 91,517,699$

<table>
<thead>
<tr>
<th>Cost head</th>
<th>Amount (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rejection cost</td>
<td>317,788</td>
</tr>
<tr>
<td>Sizing cost</td>
<td>4,500,000</td>
</tr>
<tr>
<td>Salaries</td>
<td>24,915,000</td>
</tr>
<tr>
<td>Overtime normal</td>
<td>372,000</td>
</tr>
<tr>
<td>Electrical cost (compressor, chiller, looms, lighting, etc.)</td>
<td>12,673</td>
</tr>
<tr>
<td>Steam cost</td>
<td>741768</td>
</tr>
<tr>
<td>General store</td>
<td>4,200,000</td>
</tr>
<tr>
<td><strong>Total cost</strong></td>
<td><strong>52,634,556</strong></td>
</tr>
</tbody>
</table>
Now, the per pick cost can be calculated as:

\[
\text{Cost per pick} = \frac{\text{Total cost}}{\text{Average picks}}
\]

\[
\text{Cost per pick} = \frac{52634556}{91517699} = \text{Rs.} \, 0.57
\]

The conversion cost for a particular quality can be calculated as:

\[
\text{Conversion cost} = \text{Cost per pick} \times \text{PPI}
\]

Conversion cost = 0.57 \times 80 = \text{Rs.} \, 45.6

\[
\text{Total cost} = \text{Conversion cost} + \text{Material cost}
\]

Total cost = 45.6 + 98.80 = \text{Rs.} \, 144.4

### 5.4 Profitability calculation

Profitability of any product depends on a number of factors. Specifically, for greige fabric, the profitability depends on raw material used, size %age required, loom type, customer zone, negotiation skills of marketing department and the repute of organisation in the market. Profit is usually the difference of selling price and the total cost incurred for the production of a particular fabric quantity.

\[
\text{Profit} = \text{Selling price} - \text{Total cost}
\]
5.5 Exercise

Problem 1: Calculate the weight/m² and weight/meter with and without size for fabric quality 20×16/128×60, 63" warp and weft contraction are 8.5% and 3.5%. Take size add on in warp is 9%.

Problem 2: Calculate the weight/m² and weight/meter with and without size for fabric quality 40×40/100×80, 98". The warp and weft contraction are 8.5% and 6.96% respectively. Take size add on in warp is 12%.

Problem 3: Calculate the GSM and GLM with and without size for fabric quality 30×20/145×76, 73". The warp and weft contraction are 7.5% and 5.5%. Take size add on in warp is 6%.

Problem 4: Calculate the material cost required for one yard of the following quality 30×30/91×86, 63". The warp and weft contraction are 5.5% and 4.5%.

Problem 5: Calculate the material cost required for one yard of the quality 32×21/133×80, 63". The warp and weft contraction are 5.5% and 4.5%.

Problem 6: Calculate the warp and weft contraction % for the given quality
Quality: 14×16/94×62, 63" 1/1 plain

Problem 7: Calculate the warp and weft contraction % for the given quality
Quality: 20×20/100×50, 63" 2/1 twill

Problem 8: Calculate the warp and weft contraction % for the given quality
Quality: 80×80/244×1236, 118" 4/1 satin

Problem 9: Calculate the amount of material required to produce 8000 meter of the given fabric quality: 14×16/94×62, 63" 2/1 twill
Problem 10: Calculate the amount of warp and weft material required to produce 5000 yards of the quality $20 \times 20/100 \times 50$, 63" 2/1 twill

Problem 11: Determine the warp and weft quantity for 10,000 meter of the quality $80 \times 80/244 \times 236$, 118" 4/1 satin

Problem 12: Determine maximum length of fabric that can be produced from 24 bags (to be used in warp and weft both). Quality $30 \times 30/76 \times 68$, 98" 1/1 plain

Problem 13: Determine maximum fabric length that can be produced from 1 bags (to be used in warp and weft both). Quality $40 \times 40/100 \times 80$, 71" 1/1 plain

Problem 14: Calculate the desized fabric weight per linear meter for fabric quality $30 \times 20/145 \times 76$, 70". The warp and weft contraction are 8% and 4% respectively. Take size add on in warp is 12%.

Problem 15: Calculate the amount of material (for each color) required for 4000 meter of the yarn dyed fabric produced in the following quality. The expected warp and weft contraction are 7.5% and 4.5% respectively.

Quality: $30 \times 30/81 \times 76$, 63" 1/1 plain

The color repeat along warp and weft is:

Warp: 2 Brown, 2 white

Weft: 2 Brown, 2 white

Also calculate the cost of material if yarn price is Rs125/lbs for 30/s white and Rs. 145/lbs for 30/s brown yarn.
6. **Weaving shed**

The warp sheet after sizing is stored on a beam called weaver’s beam. This beam is used on the loom for fabric production and therefore also referred as loom beam. This beam is mounted on the back of machine and fabric is produced on the front side. The fabric production on loom involves a set of certain associated motions; the primary and secondary motions.

6.1 **Warp tension**

The warp sheet on loom is under three types of tensions during weaving including constant mean tension, cyclic tension variation and random tension variation. Constant mean tension is imparted in the sheet due to take up/let off, and is usually not the cause for warp breakage. The cyclic tension variations result from shedding and beat up, and may cause weak yarns to break at high peak tension. Random tension variation is caused by different reasons (knots, entangled yarns, protruding fibres, etc.). It is important to maintain a uniform warp tension during weaving. Consider the length of warp (L) between supports (back rest and take up), which is deflected H, from mean position when a tension meter of weight W is hung from the midpoint of length.

![Diagram showing warp tension](image)

From Newtonian mechanics, the magnitude of tension (T) in the warp is equal to:

\[
T = T_1 = T_2 = \frac{W}{2 \times Sin(\alpha)}
\]
Substituting the term \( \sin(\alpha) \) by \( \frac{2H}{L} \), we get:

\[
T = \frac{W \times L}{4H}
\]

To find the height \( (H) \) that corresponds to a certain tension, we get:

\[
H = \frac{W \times L}{4T}
\]

Thus, it is possible to measure/quantify the warp tension in a simple way. This information can be passed on to duplicate the same warp tension on other looms running the same fabric quality. In general, the relation used to approximate the value of warp tension on loom (N) is:

\[
Warp\ tension\ (N) = \frac{Total\ ends}{Warp\ count}
\]

6.2 Reed count

Reed is an integral part of beat-up motion. The calculation of reed count and reed width are of highly important for defining the fabric width and end per unit width. The reed is composed of a frame with several vertical slits. These slits are called dents. The number of dents per unit length of reed is called reed count (RC). Various type of reed count systems are implemented in the textile industry such as Stockport, Radcliff, Huddersfield and Metric. These systems are defined as number of dents in a given space.

There exists other reed count systems also, which are based on the number of groups of dents in a given space. These systems include Bolton, Bradford, Blackburn, Irish, Leeds and Macclesfield. Most commonly used reed count system in Pakistan’s textile industry is Stockport, which is number of dents per two inches. The Table 6.1 and 6.2 give information on the reed count systems based on the number of dents in a given space and number of groups or beers in a given space respectively.

\[
RC_{Stockport} = \frac{Number\ of\ dents}{Number\ of\ inches} \times 2
\]

<table>
<thead>
<tr>
<th>Reed count</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stockport</td>
<td>Number of dents per 2 inches</td>
</tr>
<tr>
<td>Radcliff</td>
<td>Number of dents per 1 inch</td>
</tr>
<tr>
<td>Huddersfield</td>
<td>Number of dents per 1 inch</td>
</tr>
</tbody>
</table>

Table 6.1 System based on the number of dents in a given space
<table>
<thead>
<tr>
<th>Metric</th>
<th>Number of dents per 1 decimetre</th>
</tr>
</thead>
</table>

Table 6.2 System based on the number of groups or beers in a given space

<table>
<thead>
<tr>
<th>Reed count</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolton</td>
<td>20 dents per 24.5 inches</td>
</tr>
<tr>
<td>Bradford</td>
<td>20 dents per 36 inches</td>
</tr>
<tr>
<td>Blackburn</td>
<td>20 dents per 45 inches</td>
</tr>
<tr>
<td>Irish</td>
<td>100 dents per 40 inches</td>
</tr>
<tr>
<td>Leeds</td>
<td>19 dents per 9 inches.</td>
</tr>
<tr>
<td>Macclesfield</td>
<td>100 dents per 36 inches.</td>
</tr>
</tbody>
</table>

Similarly, total number of dents can be calculated, if reed count and width of reed is given. The reed width can be calculated if total dents and reed count is given. It is also to be noted that all types of reed counts are interchangeable. The following equation can be used to convert one count system to another count system.

\[
Required \, RC = \frac{DPI \, in \, known \, count \, system}{DPI \, in \, required \, count \, system} \times RC \, in \, known \, system
\]

Where,

- RC: Reed count
- DPI: Number of dents per inch

**Example 6.1:**

*If total number of dents in 65 inch of reed is 2600, calculate the reed count in Stockport and Metric systems.*

**Solution:**
If we have total number of dents 2600 in 65 inches of reed width, the dents per inches can be calculated by dividing the total number of dents by total width. In this case dents per inch will be 40. Since, the reed count in Stockport system is number of dents per two inches, the reed count can be calculated as:

\[
RC_{Stockport} = \frac{\text{Number of dents}}{\text{Number of inches}} \times 2
\]

\[
RC_{Stockport} = \frac{2600}{65} \times 2 = 80
\]

Since, metric system defines reed count as number of dents per 1 decimetre (1 inch = 0.254 decimetre), the reed count in Metric system can be calculated as follows:

\[
RC_{Metric} = 80 \times 0.254 = 20.32
\]

**Example 6.2:**

*Convert the 1.35 reed count of Bradford into Stockport system of reed count.*

**Solution:**

The 1.35 Bradford reed count means that there are 1.35 groups of 20 dents in 36 inches of reed.

\[
\text{Total number of dents in 36 inches} = 1.35 \times 20 = 27
\]

\[
\text{Total number of dents in 1 inch} = \frac{27}{36} = 0.75
\]

Since, Stockport reed count system calculate the number of dents per 2 inches therefore, number of dents per inch will be 0.5.

\[
\text{Required reed count} = \frac{0.75}{0.5} \times 13.5 = 20.25
\]

The 1.35 reed count of Bradford system is equal to 20.25 dents per two inch i.e. reed count in Stockport system.

**Determining Reed Count from fabric parameters:**

In textile industry, calculation of reed count and reed width are very much common against given quality. The selection of reed count depends on ends per inch (EPI) and drawing-in
of ends for a particular weave structure whereas reed width depends on contraction of cloth in weft direction. The general formula used in industry to calculate reed count is given below.

\[
Reed\ count = \frac{Ends\ per\ inch}{1 + weft\ contraction}
\]

The weft contraction is either determined using the formulas mentioned in the chapter 5, or are based on the previous running experience.

**Example 6.3:**

*Find the reed count in Stockport system for a quality having 108 ends per inch. The weft contraction is expected upto 2.5%.*

**Solution:**

The reed count can be calculated as:

\[
RC_{\text{Stockport}} = \frac{108}{1 + \frac{2.5}{100}}
\]

\[
RC_{\text{Stockport}} = 105.37
\]

6.3 **Reed width**

The reed width can be defined as the portion of reed where denting of yarns is performed. It is generally more than the cloth width, depending on the weft crimp %. For a given quality, the reed width is calculated using following formula:

\[
Reed\ width = Cloth\ width \times \frac{100 + Weft\ crimp\ %}{100}
\]

The weft crimp percentage is a significant factor while deciding the reed with. The crimp percentage is the difference between straightened thread length and the distance between the ends of the thread in the fabric as given in equation below. The details of crimp percentage can be read in Chapter 5. A general formula to calculate the weft crimp % of yarn from a given piece of fabric is given below.

\[
Weft\ crimp\ % = \left(\frac{\text{weft length} - \text{fabric width}}{\text{fabric width}}\right) \times 100
\]
Example 6.4:

A fabric of 60 inches of width is analysed, the mean weft length is 62.2 cm. Determine the weft crimp percentage and also calculate the reed width.

Solution:

The weft crimp is determined by considering the fabric width and the mean length of weft yarn.

\[
Weft \ crimp \% = \frac{62.2 - 60}{60} \times 100
\]

Weft crimp \% = 3.67%

Now, the reed width is calculated as:

\[
Reed \ width \ (inches) = 60 \times \frac{100 + 3.67}{100}
\]

Reed width (inches) = 63.67

6.4 Maximum ends per inch (EPI\text{\_}max)

The maximum number of ends per inch can be predicted by extending the Peirce’s geometrical model by soft computing. This information is valuable to the weavers to decide the weave possibility of a given construction. Maximum number of ends per inch can be calculated using following formula;

\[
EPI_{\text{max}} = \frac{\text{Weave repeat ends}}{\text{Yarn diameter} \times (\text{Weave repeat intersection} + \text{Weave repeat ends})}
\]

Whereas yarn diameter can be calculated using equation.

\[
\text{Yarn diameter} = \frac{1}{28 \times \sqrt{\text{Yarn count}}}
\]

Some typical weave design can accommodate maximum ends per inch (EPI\text{\_}max) are given in the Table 6.3:

Table 6.3 Maximum ends/inch for basic weaves
Weave design | Maximum number of ends per inch
---|---
Plain | $14 \times \sqrt{\text{Yarn Count}}$
Drill | $28 \times \frac{4}{6} \times \sqrt{\text{Yarn Count}}$
Satin | $28 \times \frac{5}{7} \times \sqrt{\text{Yarn Count}}$

### 6.5 Loom production

The textile industry runs on the profit of loom production. It mainly depends on picks per inch, RPM (revolution per minute) of motor and width of fabric. However, quality construction of fabric and loom maintenance also plays a role in loom production. The loom production is calculated as the fabric produced in an hour, a shift or a day. The monthly and annual production of loom decides the profit of industry. The production of one loom for a given time ($t$) can be calculated using equation:

$$Loom\ production = \frac{Loom\ speed \times 60 \times t}{PPI \times 39.37}$$

Loom speed is given in terms of RPM and is equal to the revolution per minute of motor.

60 is a constant for the conversion of minute into hour

“$t$” is the time in hours

PPI is the picks per inch

39.37 is a constant for the conversion of inches into meters

**Example 6.5:**

*A loom running with 900 rpm will have to produce a fabric of 90 picks per inch. Calculate the metres of fabric can be produced in one day.*

**Solution:**

A loom running with 900 rpm will insert 900 picks in one minute, so it can produce a 10 inch of fabric in one minute. 10 inch of fabric is equal to $10/39.37 = 0.25$ meters of fabric. In one day, the fabric produced will be 365.76 meters.

$$Loom\ production = \frac{900 \times 60 \times 24}{90 \times 39.37}$$

$Loom\ production = 365.76$ meters
It is to be noted that, practically, actual production is always less than the calculated productions. The ratio of actual production to calculated production is called efficiency of loom.

\[
\text{Loom efficiency} = \frac{\text{Actual production}}{\text{Calculated production}} \times 100
\]

Normally, loom efficiency is displayed by each loom panel and we are interested to know about the actual production of fabric in order to complete the customer order. Equations mentioned earlier can be used to calculate the actual production of fabric and time required to complete the customer order.

**Example 6.6:**

*A loom is running on 97% efficiency and its calculated production is 365.76 meters. Calculate the actual production per day and also time required to complete the customer order of 1000 meter.*

**Solution:**

The actual production will be calculated as follows;

\[
\text{Actual production} = 365.76 \times \frac{97}{100}
\]

\[
\text{Actual production} = 354.79 \text{ meters}
\]

If a loom can produce 354.79 meters of fabric so time required to produce the1000 meters of fabric will be:

\[
\text{Time to produce 1000 m fabric} = \frac{1000}{354.97}
\]

\[
\text{Time to produce 1000 m fabric} = 2.81 \text{ days}
\]

6.6 Fabric shrinkage%

Fabric shrinkage calculation is mostly used to determine the shrinkage of width in Lycra qualities. Lycra qualities are the fabric constructions having core spun lycra/elastane yarn running in the weft direction. This lycra yarn may be stretched more than 100% of the original yarn length. Therefore, the lycra qualities are washed to observe the shrinkage percentage after washing. The shrinkage can be calculated as;
Fabric shrinkage = \( \frac{W_{bw} - W_{aw}}{W_{bw}} \times 100 \)

\( W_{bw} \) is the width of fabric before washing

\( W_{aw} \) is the width of fabric after washing

6.7 Weaving shed Management

6.7.1 Air consumption calculation

Air-jet looms utilize compressed air for weft insertion and are capable of producing fabric at a very high rate. The air guiding system is controlled by a number of nozzles, sub-nozzles and the pneumatic valves. The weft is inserted due to the frictional pull of the air on the weft yarn. Therefore, the air consumption of Air-Jet looms depends on weft yarn count, fabric width, loom speed and reed count. It is quite challenging to adjust the required air volume for a given quality, however, following regression model\(^1\) can be used to predict the air consumption on loom.

Compressed Air Consumption (Litres/second)

\[
= 6.10770 - 0.0346718 X_1 + 0.0155271 X_2 - 0.000147579 X_3 + 0.0365014 X_4 + 0.000312117 X_1^2 \\
+ 0.00114788 X_2^2 - 0.0000338015X_3X_4 + 0.000127147 X_4X_3 - 0.000858253 X_2X_4
\]

Where,

- \( X_1 \) weft yarn count
- \( X_2 \) fabric width
- \( X_3 \) loom speed
- \( X_4 \) Reed count

On air jet loom, the air consumption varies from 13 to 40 liters/second. It increases with increase in fabric width and loom speed, while decreases as the weft yarn count and reed count increases. Fabric width is the most dominant factor affecting the air consumption. The statistical model has also been validated by the authors practically.

**Example 6.7:**

*Calculate the air consumption in litres/second for a quality 10×10/100×60, 63”, where reed count of 74.50 dents per two inches was used. The loom was running on 650 rpm.*

**Solution:**

The compressed air consumption in litres/second can be calculated as:

\[
\text{Compressed Air Consumption (Litres/second)} = 6.10770 - 0.0346718 \times 10 + 0.0155271 \times 63 - 0.000147579 \times 650 + 0.000312117 \times (63)^2 - 0.00038015 \times 10 \times 74.50 + 0.000127147 \times 63 \times 650 - 0.000858253 \times 63 \times 74.50
\]

Compressed Air Consumption (Litres/second) = 6.10770 – 0.346718 + 0.978207 - 0.095926 + 2.7193543 + 0.0312117 + 4.55593572 - 0.251821175 + 5.20666965 - 4.028210456

Compressed Air Consumption = 14.87 litres/second

**6.7.2 Weaver’s allocation**

Weaver’s allocation refers to the number of looms allocated for a weaver. It can be also defined the weaver’s work load. It mainly depends on the loom stoppages (such as warp stop, weft stop, mechanical stops and other stops) and time require to mend the stops. Each textile mills has its own standard of stops per loom and mending/repairing time of one stop. Normally 20% of total time is reserved for a weaver’s rest. 62.5% of the remaining time is used for running the loom i.e. mending and repairing of warp and weft yarns. Rest of the time is used for patrolling. Normally, six minutes are required for patrolling of six looms. Work load of weaver can be calculated as given in Example 6.8.

**Example 6.8:**

*If an average stoppage time of looms is 5 minutes per hour. Calculate the work load of weaver, if 20% time is reserved for rest, 62.5% of the reaming time is used for mending/repairing. Also calculate the number of patrol, the weave can made in one hour.*

**Solution:**

\[
\text{Time reserved for rest in an hour} = \frac{60 \times 20}{100}
\]

Time reserved for rest in an hour = 12 min
Now, 62.5% of remaining time will be used for mending/repairing.

Remaining time = 60 – 12 = 48 min

\[ Time \text{ for mending/repair} = \frac{48 \times 62.5}{100} \]

Time for mending/repair = 30 min

The remaining time apart from rest and mending/repair time will be

Remaining time after mend and rest = 60 – 12 – 30 = 18 min

The number of patrol a weave can make:

Number of patrols = \frac{18}{6} = 3 \text{ patrol}

6.7.3 Number of air changes

The number of air changes is generally expressed in terms of air changes per hour. It is also termed as the air change rate. The air change rate measures volume of air added or removed per unit volume of the shed. The air changes per hour is defined as the how many times the air of shed is replaced. For the calculation of number of air changes, it is desirable that the air of shed is uniformly mixed. Also the amount of air leaving and entering the shed must be same.

\[ N = \frac{Q \times 60}{V} \]

Where,

\( N \) = number of air changes per hour

\( Q \) = Volumetric flow rate of air in cubic feet per minute (CFM)

\( V \) = Space volume \( L \times W \times H \), in cubic feet

Example 6.9:

Calculate the number of air changes in the shed, if volumetric flow rate of air is 350 CFM and the dimensions of shed are 25’×20’×10’.
Solution:

The volume of shed can be calculated as:

\[
\text{Volume of shed} = 25 \times 20 \times 10
\]

\[
\text{Volume of shed} = 5000 \text{ ft}^3
\]

Now, the number of air changes can be calculated as:

\[
\text{Number of air changes} = \frac{350 \times 60}{5000}
\]

Number of air changes = 4.2

6.8 Fabric inspection

Fabric inspection can be defined as the visual examination or review of fabric produced. It is common to inspect “first meter” of each roll during fabric production. The first meter is taken by maintenance in-charge and handed over to quality supervisor or folding inspector. In first meter, the ends per inch, picks per inch, warp count and brand, weft count and brand, width of the fabric, reed, and weave design is inspected. The first meter is inspected as soon as it is produced to avoid fabric faults in subsequent fabric production.

Apart of first meter, each roll of fabric and also inspected in folding department, where fabric roll is graded as A or B grade etc. Some mendable faults are also mended during inspection to improve the grade of fabric roll. There are various grading systems of fabric inspection are acceptable which are discussed in section Grading systems.

6.8.1 Grading systems

Fabric grading systems are used to provide the quantitative quality of fabric. Most commonly, there are two types of systems exist i.e. 4- point system and 10- point system. However, 2.5- point system and other grading system do exist as well. The 4- point grading system was designed by American Apparel Manufacturers Association (AAMA). Two types of faults are inspected in this grading system i.e. length wise faults and hole or opening. The grading points under 4- point system are provided in Table 6.3. Total defect points per 100 yard square are calculated using below equation. If fabric rolls contain less than 40 points per 100 yard square are considered “A Grade” quality and as an acceptance criteria. If fabric rolls containing more than 40 points per 100 yards square are considered “B Grade”.

123
Table 6.3 Defects point grading table

<table>
<thead>
<tr>
<th>Length of defect in Fabric</th>
<th>Points allotted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 3 inch</td>
<td>1</td>
</tr>
<tr>
<td>Over 3 inch up to 6 inch</td>
<td>2</td>
</tr>
<tr>
<td>Over 6 inch up to 9 inch</td>
<td>3</td>
</tr>
<tr>
<td>Over 9 inch</td>
<td>4</td>
</tr>
<tr>
<td><strong>Holes or Opening</strong></td>
<td></td>
</tr>
<tr>
<td>1 or less</td>
<td>2</td>
</tr>
<tr>
<td>Over 1 inch</td>
<td>4</td>
</tr>
</tbody>
</table>

**Example 6.10: A fabric roll 120 yards long and 46 inch wide contains following defects.**

<table>
<thead>
<tr>
<th>Types of fault</th>
<th>Number of faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects up to 3 inch length</td>
<td>4</td>
</tr>
<tr>
<td>Defects from 3 to 6 inch length</td>
<td>3</td>
</tr>
<tr>
<td>Defects from 6 to 9 inch length</td>
<td>2</td>
</tr>
<tr>
<td>Defect over 9 inch length</td>
<td>1</td>
</tr>
<tr>
<td>Hole over 1 inch</td>
<td>1</td>
</tr>
</tbody>
</table>

**Solution:**

Calculate the number of fault points for each category.
<table>
<thead>
<tr>
<th>Defects up to 3 inch length</th>
<th>4</th>
<th>4x1 points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects from 3 to 6 inch length</td>
<td>3</td>
<td>3x2 points</td>
</tr>
<tr>
<td>Defects from 6 to 9 inch length</td>
<td>2</td>
<td>2x3 points</td>
</tr>
<tr>
<td>Defect over 9 inch length</td>
<td>1</td>
<td>1x4 points</td>
</tr>
<tr>
<td>Hole over 1 inch</td>
<td>1</td>
<td>1x4 points</td>
</tr>
</tbody>
</table>

In the next step all the defect points are added to determine the total defect points.

Total defect points = 4 + 6 + 6 + 4 + 4

Total defect points = 24

Now, the Points/ 100 sq. yards are calculated as:

$$ Points/\text{100 sq. yards} = \frac{Total\ defect\ points \times 3600}{Fabric\ length\ (yards) \times Width\ (inches)} $$

$$ Points/\text{100 sq. yards} = \frac{24 \times 3600}{120 \times 46} $$

Points/ 100 sq. yards = 15.652 points

6.8.2 Points per linear meter/square meter

The fabric quality after inspection is usually expressed in terms of points per linear square meter. It can be calculated as follows;

$$ Points/ linear\ sq.\ meter = \frac{Total\ points}{Fabric\ length\ (m) \times Width\ (m)} $$

Example 6.11: A fabric roll 130 yard long and 45 inch wide contains the following defects:
### Calculate the points per linear square meter in 4-point grading system.

**Solution:**

The number of fault points are calculated for each category.

<table>
<thead>
<tr>
<th>Types of faults</th>
<th>Number of faults</th>
<th>Total points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects up to 3 inch length</td>
<td>6</td>
<td>6x1 points</td>
</tr>
<tr>
<td>Defects from 3 to 6 inch length</td>
<td>5</td>
<td>5x2 points</td>
</tr>
<tr>
<td>Defects from 6 to 9 inch length</td>
<td>2</td>
<td>2x3 points</td>
</tr>
<tr>
<td>Defect over 9 inch length</td>
<td>1</td>
<td>1x4 points</td>
</tr>
<tr>
<td>Hole over 1 inch</td>
<td>1</td>
<td>1x4 points</td>
</tr>
</tbody>
</table>

In the next step all the defect points are added to determine the total defect points.

\[
\text{Total defect points} = 6 + 10 + 6 + 4 + 4
\]

Total defect points = 30

Now, the Points/ linear sq. meter are calculated as:
Points/ linear sq. meter = \frac{Total\ defect\ points}{Fabric\ length\ (m) \times Width\ (m)}

The fabric length and width are first converted into meters

\[
Points/\ linear\ sq.\ meter = \frac{30}{(130 \times 1.0936) \times (45/39.37)}
\]

\[
Points/\ linear\ sq.\ meter = \frac{30}{142.168 \times 1.143}
\]

Points/ linear sq. meter = 0.185 points

6.9 Exercise

Problem 1: If total number of dents in 71 inches of reed are 2600. One end is drawn through one dent of reed. Calculate the reed count in Stockport and Huddersfield systems.

Problem 2: Convert 20 RC of Metric system into following Reed count systems;

Stockport
Radcliff
Huddersfield

Problem 3: Convert 12 RC of Irish system into following Reed count systems;

Bolton
Bradford
Blackburn
Leeds
Macclesfield
Problem 4: If total number of dents in 65 inches of reed are 3800. Three ends are drawn through one dent of reed. Calculate the reed count in Stockport and Metric systems.

Problem 5: Find the reed count of following qualities with weft contraction of 3.2%. The required ends per dent are 2.

Quality: 12×12/80×60-63”

Quality: 60×60/140×100-71”

Problem 6: Find the reed count of a given quality with total number of ends 6800. The required working width is 65” and ends per dent are 3.

Problem 7: Find the reed count of a given quality with total number of ends 5600. The expected weft contraction in the quality is 6%, whereas the required ends per dents are 4.

Problem 8: Find the required reed with for 63” wider fabric with expected weft contraction of 2.8%.

Problem 9: Calculate the weft crimp percentage of 105” wider fabric. The weft length in the fabric was found to be 107.88”.

Problem 10: Estimate the yarn diameter of 20/1 Ne.

Problem 11: A loom running with 760 rpm will have to produce a fabric with 42 picks per inch. Calculate the metres of fabric can be produced in one day with following efficiency.

100%

97%
Problem 12: Calculate the fabric shrinkage for 63” wider cloth whose width was reduced to 60.7” after washing.

Problem 13: Calculate the air consumption in litres/second for a quality of $30 \times 30/76 \times 76-63”$, where reed count of 72 dents per two inches was used. The loom was running on 880 rpm.

Problem 14: If an average stoppage time of looms is 4.5 minutes per hour. Calculate the work load of weaver, if 20% time is reserved for rest, 62.5% of the reaming time is used for mending/repairing. Also calculate the number of patrol, the weaver can make in one hour.

Problem 15: A fabric roll 250 yard long and 63 inch wide contains the following defects:

<table>
<thead>
<tr>
<th>Types of fault</th>
<th>Number of faults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects up to 3-inch length</td>
<td>12</td>
</tr>
<tr>
<td>Defects from 3 to 6-inch length</td>
<td>7</td>
</tr>
<tr>
<td>Defects from 6 to 9-inch length</td>
<td>12</td>
</tr>
<tr>
<td>Defect over 9-inch length</td>
<td>2</td>
</tr>
<tr>
<td>Hole over 1-inch</td>
<td>1</td>
</tr>
</tbody>
</table>

Calculate the points per linear square meter in 4- point grading system.
7. Fabric Geometry

Fabric geometry is an important parameter in determining the behaviour of the fabric under specific conditions. For instance, if there is more tension on warp, the crimp in the weft yarn will increase and vice versa. Similarly, fabric shrinks due to fibre swelling when dipped in water. Therefore, study of fabric geometry helps to:

- Predict the maximum sett (density) of fabric that can be woven
- Derive relationship between geometrical parameters
- Predict mechanical properties by combining fabric geometry with yarn properties
- Understand fabric performance (handle and surface effects)

7.1 Structural parameters of woven fabrics

From the previous research on the geometric theories introduced above, several parameters could be extracted to characterise the fabric geometry. In this section, a general
description of every parameter will be given. Some of them need not be calculated but can only be measured.

7.1.1 Yarn diameter

If the yarn is considered circular in cross-section, then it must have some diameter. The diameter of yarn is directly related to the linear density of yarn, which depends on the fibre fineness and number of fibres in the cross section of yarn. The yarn diameter can be calculated using the following relation.

$$\frac{1}{d} = 29.3 \times \sqrt{\frac{N}{v}}$$

Where v is the specific volume and expressed as the ratio of volume occupied by a material to that of the same weight of water under compression. The following relation is used to calculate the specific volume of fabric.

$$v = \frac{\text{Fabric thickness (cm)}}{\text{Fabric mass (g/cm}^2 \text{)}}$$

For cotton woven structure the specific volume is 1.1, and the diameter of yarn is:

$$d (\text{inches}) = \frac{1}{28\sqrt{N}}$$

$$d (\text{mm}) = \frac{0.9}{\sqrt{N}}$$

Example 7.1:

Calculate the yarn diameter in inches and mm for a 30/s yarn.

Solution:

As we know that,

$$Yarn\ diam (\text{inches}) = \frac{1}{28\sqrt{30}}$$

$$Yarn\ diam (\text{inches}) = 0.00652 \text{ inch}$$
\[
Yarn \text{ dia (mm)} = \frac{0.9}{\sqrt{N}}
\]

\[
Yarn \text{ dia (mm)} = \frac{0.9}{\sqrt{30}}
\]

Yarn diameter = 0.164 mm

7.1.2 Fabric thickness

Fabric thickness is usually a neglected term, but it is highly important in determining the properties of fabric. Fabric thickness, \( t \) depends on the warp and weft yarns used in the fabric. If yarn is supposed to be circular in shape, the minimum thickness that can be achieved is the sum of warp and weft diameters.

\[
Fabric \text{ thickness, } t_{\text{min}}(mm) = d_1 + d_2
\]

Where, \( d_1 \) and \( d_2 \) are warp and weft diameters in mm.

The maximum fabric thickness is achieved when one of the yarns (warp or weft) is straightened as far as possible. For an open cloth, the yarns may be straightened to zero crimp, giving maximum fabric thickness.

\[
Fabric \text{ thickness, } t_{\text{max}}(mm) = d_1 + 2d_2
\]

\[
Fabric \text{ thickness, } t_{\text{max}}(mm) = 2d_1 + d_2
\]

The fabric thickness can also be approximated if the fabric areal density and fabric volume is known. The fabric volume involves some complexities, as fabric contains some inter yarn and intra yarn spaces.

\[
Fabric \text{ thickness, } t = \frac{\text{Fabric areal density}}{\text{Fabric volume}}
\]
Where, fabric thickness is in meter, fabric areal density in Kg/m² and fabric density in Kg/m³.

Example 7.2:

Calculate the maximum and minimum fabric thickness that can be achieved with the fabric quality 40×50/200×138, 75”.

Solution:

The $d_1$ and $d_2$ can be calculated as:

$$d_1 = \frac{0.9}{\sqrt{40}}$$

$d_1 = 0.142$ mm

$$d_2 = \frac{0.9}{\sqrt{50}}$$

$d_1 = 0.127$ mm

Now, for the minimum fabric thickness,

$$Minimum \ fabric \ thickness \ (mm) = 0.142 + 0.127$$

$$Minimum \ fabric \ thickness = 0.269 \ mm$$

The maximum fabric thickness can be calculated in two ways:

$$Maximum \ fabric \ thickness \ (mm) = 0.142 + 2(0.127)$$

$$Maximum \ fabric \ thickness = 0.396 \ mm$$

$$Maximum \ fabric \ thickness \ (mm) = 2(0.142) + 0.127$$

$$Maximum \ fabric \ thickness = 0.411 \ mm$$
7.1.3 Cover factor

The fabric cover factor is defined as the fraction of total fabric area that is covered by its constituent yarns. Considering yarn with a circular cross section, the cover factor \( K \) is defined as a ratio of yarn diameter \( d \) and yarn spacing \( p \).

\[
Cover \ factor, K = \frac{d}{p}
\]

\[
Cover \ factor, K = \frac{E}{28\sqrt{N}}
\]

Where, \( E \) is yarns per inch \( (E = 1/p) \) and \( N \) is yarn count.

For direct system:

\[
Cover \ factor, K = n . d
\]

Where \( n \) is number of yarns per centimetre, \( d \) is diameter in cm.

As the yarns run along two directions (warp and weft) in case of woven factors, the cover factor is calculated both for warp and weft yarns, separately. The subscript 1 and 2 denote warp and weft respectively. The overall cover factor from warp and weft cover factors is calculated as:

\[
K = K_1 + K_2 - K_1 K_2
\]

7.1.4 Yarn crimp

The yarn crimp is the extra length of yarn consumed in undulations due to interlacement of yarn and is expressed as percentage.

\[
c_1(\%) = \left( \frac{l_1}{p_2} - 1 \right) \times 100
\]

\[
c_2(\%) = \left( \frac{l_2}{p_1} - 1 \right) \times 100
\]

Where, \( p \) is thread spacing and \( l \) is the length of yarn axis between planes containing the axes of consecutive cross threads.

7.1.5 Fabric areal density

The fabric areal density is expressed as mass of a unit area of fabric. It is generally expressed in terms of GSM, i.e. grams per square meter. Following formula is used to calculate the GSM of a fabric:

\[
GSM = \frac{T_1 n_1}{10} (1 + c_1) + \frac{T_2 n_2}{10} (1 + c_2)
\]
Where $T_1$, $T_2$ are warp and weft yarn tex; $n_1$, $n_2$ are ends and picks per cm and $c_1$, $c_2$ are the warp and weft crimp.

7.2 Fabric geometry models

The textile fabrics have a complex structure depending on the irregularity in the yarn cross section shape and the crimp induced in yarn during weaving. To represent the configuration of threads in woven fabrics, many different forms of geometry have been put forward by textile researchers, considering fabrics as a network of identical unit cells in the form of crimp waves and constant yarn cross-section. Based on the circle, ellipse and rack-track cross-sectional shape, four fabric geometry models have been presented by the researchers namely:

- Pierce’s model
- Modified Pierce’s model
- Kemp’s race track model
- Hearle’s lenticular model

7.2.1 Pierce’s model

The systematic study of woven fabric geometry was started by Peirce’s in 1937. The Peirce’s model of plain-weave fabrics is shown in figure below.

![Figure 7.1 Pierce’s model with circular cross-section geometry of plain weave](image)

In this model, a two-dimensional unit cell (or repeat) of fabric was built up by superimposing linear and circular yarn segments to produce the desired shape. The yarns were assumed to be circular in cross-section and highly incompressible, but at the same time perfectly flexible so that each set of yarns had a uniform curvature imposed upon it by the circular cross-
sectional shape of the interlacing yarns. The relationship between geometrical parameters such as thread-spacing, weave crimp, weave angle and fabric thickness forms the basis of analysis in this model.

Here, d is yarn diameter, p is yarn spacing, h is maximum displacement of yarn axis normal to fabric plane (crimp height), θ is angle of yarn axis to fabric plane (weave angle in radians), l is length of yarn axis between the planes through the axes of consecutive cross-threads and c is crimp. Now, from the cross sectional view, different structural parameters can be calculated as:

\[ p_1 = (l_2 - D\theta_2)\cos\theta_2 + D\sin\theta_2 \]
\[ p_2 = (l_1 - D\theta_1)\cos\theta_1 + D\sin\theta_1 \]
\[ h_1 = (l_1 - D\theta_1)\sin\theta_1 + D(1 - \cos\theta_1) \]
\[ h_2 = (l_2 - D\theta_2)\sin\theta_2 + D(1 - \cos\theta_2) \]
\[ D = d_1 + d_2 = h_1 + h_2 \]

The equations for crimp have already been defined in the earlier section. Hence, there are seven equations involving 11 variables. Having any four known variables, the equations can be solved for remaining variables. This model is convenient for calculation, and is especially valid in very open structures. But the assumptions of circular cross-section, uniform structure along the longitudinal direction, perfect flexibility, and incompressibility are all unrealistic, which leads to the limitations on application of this model.

7.2.2 Modified Pierce's model

A high inter-yarn pressure is developed while producing tightly woven fabrics. This pressure causes considerable yarn flattening, normal to the plane of fabric. This effect was recognised by Peirce, and he later proposed an elliptical section theory as shown in figure below. To avoid the complexities, he approximated the cross section of yarn with the minor axis diameter of the elliptic section. This modified model is good for reasonable open fabrics, but it cannot be applied for jammed fabric.
The yarn flattening factor, $e$ is defined as:

$$Yarn\ flattening\ factor,\ e = \frac{b}{\sqrt{a}}$$

Where “a” and “b” are the major and minor axis of ellipse respectively. If $d$ is assumed as the diameter of the equivalent circular cross-section yarn, then

$$d = \sqrt{ab}$$

$$h_1 + h_2 = d_1 + d_2 = b_1 + b_2$$

$$b_1 + b_2 = h_1 + h_2 = \frac{4}{3} (p_1 \sqrt{c_2} + p_2 \sqrt{c_1})$$

$$h_1 + h_2 = d_1 + d_2 = \frac{1}{280} (\sqrt{T_1} + \sqrt{T_2})$$

### 7.2.3 Kemp’s race track model

To overcome the jammed structure, Kemp proposed a racetrack section to modified cross-section shape of yarn. This model consisted of a rectangle enclosed by two semi-circular ends and had the advantage that it allowed the relatively simple relations of circular-thread geometry, already worked out by Pierce, to be applied to a flatted threads.
The maximum and minimum diameters of yarn cross-section are represented by “a” and “b” respectively. The basic equations are modified for this model as under:

\[ p_2' = p_2 - (a_2 - b_2) \]

\[ l_1' = l_1 - (a_2 - b_2) \]

\[ c_1' = \frac{l_1' - p_2'}{p_2'} \]

Substituting the values of \( l_1' \) and \( p_2' \) in the above equation, we get:

\[ c_1' = \frac{c_1p_2}{p_2 - (a_2 - b_2)} \]

\[ c_2' = \frac{c_2p_1}{p_1 - (a_1 - b_1)} \]

\[ h_1 = \frac{4}{3}p_2' = \sqrt{c_1'} \]

\[ h_2 = \frac{4}{3}p_1' = \sqrt{c_2'} \]

\[ H1 + h_2 = B = b_1 + b_2 \]
7.2.4 Hearle’s lenticular model

The model based on the lenticular cross section of fabric was presented by Hearle and Shanahan (1978) as shown in Figure 7.4. The lenticular model is considered to be the most general model mathematically.

The relations derived for lenticular section geometry are:

\[
Yarn \ flattening \ factor, \ e_i = \frac{a_i}{b_i}
\]

\[
p_i = (l_i - D_j \theta_j) \cos \theta_j + D_j \sin \theta_j
\]

\[
h_{ii} = (l_i - D_i \theta_i) \sin \theta_i (1 - \cos \theta_j)
\]

\[
D_i = 2R_j + b_i
\]

\[
l_{cj} = D_i \theta_i
\]
Substituting $D_1 = D_2 = d_1 + d_2 = D$ into the above equations, the Peirce’s geometry can be obtained as:

\begin{align*}
    p_1 &= (l_2 - D\theta_2)\cos\theta_2 + D\sin\theta_2 \\
    p_2 &= (l_1 - D\theta_1)\cos\theta_1 + D\sin\theta_1 \\
    h_1 &= (1 - D\theta_1)\sin\theta_1 + D(1 - \cos\theta_1) \\
    h_2 &= (1 - D\theta_2)\sin\theta_2 + D(1 - \cos\theta_2)
\end{align*}

\[ h_1 + h_2 = b_1 + b_2 = D \]

7.2.5 **Limitations of geometrical models**

There exist some limitations for the geometrical models proposed by the researchers. Some of the limitations include:

1. The fabrics are complicated materials that do not conform even approximately to any of the ideal features suggested by these four fabric models.
2. The calculation of geometrical parameters is not easy in practice.
3. The relationship between fabric mechanics (tensile, elongation, bending) to fabric geometry is not fully explored.
Specialty fabrics

Certain fabrics in use have unique fabric structure and require special manufacturing procedures. Some common examples of such fabrics include terry towel, ball warping for denim, sample development on small scale, etc. This chapter focuses on the calculations involved with the manufacturing of these specialty fabrics.

8.1 Terry towel

A terry towel is called as a textile product having loop pile on one or both sides generally covering the entire surface or forming strips, checks, or other patterns (with cross hems or fringes and side hems or selvages).

8.1.1 Parts of a conventional terry towel

A terry towel consists of different parts including the end hem, cam, dobbi, terry body and selvage, as shown in Figure 8.1. It is necessary to know that it is not necessary for all parts to come in every towel.

End hem Portion

Stitched portion of towel having flat weave at the ending of towel in length wise direction is known as end hem. It could have plain weave or any other design.

Cam Portion

Terry portion after end hem or dobbi or in between the dobbi is known as cam. It could be on one or both sides.

Dobby Border (fancy portion)
Design portion of towel as you can see in figure 1 is known as dobby border. It could be on one or both sides of towel.

**Body of towel**

Central pile portion of towel is known as body of towel.

**Header**

If there is design portion of any size in towel comes after end hem than that portion plus finish stitched end hem is referred as header.
Figure 8.1 Dobby towel

**Cam border**

Plain portion of towel having terry weave in between two cams is known as cam border as shown in Figure 8.1.

**Cut Panama**

The cut panama is extra plain portion of towel other than overall length of towel which is made between two towel having no weft, basically cut panama is joining part of two towel panels from where two cut out or separated

**Hem/Selvedge**

The top and bottom of a towel will have a hem seam. This is because the towels are made on a large continuous roll, and are then cut individually. In general terms, the hem can be a lock stitch or a chain (continuous) stitch. The advantage of a lock stitch hem is that if one part of the seam is pulled, the whole hem will not unravel. A chain stitch, if part of it is pulled, will unravel. This is an important durability feature, and most U.S. made towels feature lock stitch hems.

### 8.1.2 General calculations

The pick density in greige fabric (towel), i.e. picks/inch is basically pick density of a terry portion and is calculated using the following relation.

- Greige picks/inch = Body picks/inch + 2
- Finished picks/inch = Body picks/inch + 3

Similarly, the warp density in greige and finished towel is calculated as:

- Greige ends/inch = Reed count × 2 × 1.04
- Finished ends/inch = Reed count × 2 × 1.1
Where 1.04 and 1.1 are the contraction factor for greige and finished towels, respectively.

**Example 8.1:**

*Calculate greige ends/inch, and greige pick/inch if reed count is 27.5, towel body pick/inch are 42?*

**Solution:**

The greige ends/inch are calculated as:

\[
\text{Greige ends/inch} = \text{Reed count} \times 2 \times 1.04
\]

\[
\text{Greige ends/inch} = 27.5 \times 2 \times 1.04 = 57.2
\]

\[
\text{Greige picks/inch} = \text{Body picks/inch} + 2
\]

\[
\text{Greige picks/inch} = 42 + 2 = 44
\]

**Example 8.2:**

*Calculate the reed count, if greige ends/inch = 61.36?*

**Solution:**

The reed count from greige ends/inch is calculated as:

\[
\text{Reed count} = \frac{\text{Greige ends/inch} \times 2 \times 1.04}{2}
\]

\[
\text{Reed count} = \frac{61.36 \times 2 \times 1.04}{2} = 127.62
\]

To make any towel, general parameters which are required to measure are weight in grams, pile to pile length in inches, ground end length in inches, greige weight per towel, overall width of towel, overall length of towel. These all parameters are required to measure in weaving for all types of towel.
Let’s talk about common terms used for all types of towel and which are involved in calculation of towel, all terms will be discussed one by one

**Case 1: Terry Towel with plain end hem**

*24.65" x 48"; 8 lbs/dzn*

Plain border = 3.1 cm

Terry bar = 7.5 cm

End hem (plain) = 1.5 cm
Figure 8.2 Terry towel with plain end hem

Figure 8.2 is the bath towel with plain border and plain end hem, terry bar is another name of cam and plain border is that portion of towel having plain weave. Below mentioned parameters are used to make this towel.

Pile to pile length (in inches) is measured from one side of a towel to other side of towel excluding end hems of both sides, and is calculated by the given formula:

\[
Pile \ to \ pile \ length \ (inches) = \left( \frac{L \times 2.54 - S}{2.54} \right) \times (1 + 5\%)
\]

Where, L is the overall length (inches) and S is the stitched finish end hem (cm) of both sides.

Ground end length is measured from one side of towel to other side of towel including end hems which is calculated by adding pile to pile length. Below mentioned formula will give ground yarn length.

Ground end length(inches) = [Pile to pile length (inches) + [Cut Panama(inches)\(1 + 5 \%\)]]

The pile portion (inches) is the term used for the terry portion of a towel. It includes both cams and body of towel; and is equal to pile to pile length when towel has no fancy border. Otherwise, the fancy border is excluded from pile to pile length.

**Case 2: Bath towel having border on both sides and end hem other than plain**

**Bath**

End hem = 1.5 cm

Terry cam = 8.89 cm

Satin weave = 1.0 cm

Diamond weave = 3.08 cm

Satin weave = 1.0 cm

Total border width = 5.08 cm
Figure 8.3 Dobby border towel

Figure 8.3 is the bath towel having border on both sides and end hem other than plain. Parameters which are involved in making this towel have been discussed one by one below, remember all sizes that are being used in formula are finish sizes.

Pile to pile length (in inches) is measured from one side of a towel to other side of towel excluding end hems of both sides which is calculated by the formula discussed earlier. Ground end length is measured from one side of towel to other side including all doby borders, end hems and cut panama which is described by formula, here the fancy size is combination of doby borders and end hem

\[ \text{Ground end length} = \text{Pile to pile length} + [\text{Cut panama} \times (1 + S\%)] + [\text{Fancy size} \times (1 + S\%)] \]

Where, S% is the shrinkage % of towel and its value is usually taken as 5%. All the lengths mentioned in equation have same units, i.e. either inches or cm.

The Pile to Pile portion of terry includes cams and body of towel. It can be calculated by using the below formula
Pile portion (inches) = Pile to Pile length (inches) – Finish Border size (inches)

Case 3: Towel with header at one side and hem at other side

1. Pile to pile length will be measured by excluding stitched header of one side and stitched end hem of other side as you can see in below formula.

\[
Pile \text{ to pile length (inches)} = \left[ \frac{(L \times 2.54) - S_1}{2.54} \right] \times (1 + 5\%)
\]

Where, \(S_1\) is the sum of stitched finish header of one side and stitched end hem, expressed in cm and \(L\) is used for overall finish length.

2. Pile to pile length is described as portion of towel measured excluding finish header size of both side as you can see in below formula.

Figure 8.4 Towel with header

Figure 8.4 shows that header is present at one side of towel while other side has only end hem. Parameters which required for weaving this towel are described below.
Pile to pile length (inches) = \[ \left( \frac{(L' \times 2.54) - S_2}{2.54} \right) \times (1 + 5\%) \]

Where \( S_2 \) is the stitched finish header in cm of both sides and \( L' \) is overall length.

3. Ground end length will be measured from one side of towel to other side of towel including all end hems dobbay borders and cut panama. Ground end length will be same for both cases. All sizes used in below formula will be finish sizes and fancy size word used for size of design portion that could be only border or border and end hem both depending upon type of towel.

\[ \text{Ground end length} = \text{Pile to pile length} + [\text{Cut panama} (1 + S_1 \%)] + [\text{Fancy size} (1 + S_2 \%)] \]

Where, \( S_1 \% \) and \( S_2 \% \) are the shrinkage \% of towel and their values are usually taken as 5\% and 2\% respectively. All the lengths mentioned in equation have same units, i.e. either inches or cm.

8.1.3 Total picks
Total picks mean picks in the whole towel. It includes picks of terry portions, end hems, cut panama and dobbay border or header. Terry picks is the picks of terry portion including all cams and body of towel.

\[ \text{Terry picks, TP} = [\text{PP} (1 + 2\%)] \times \text{Body picks/inch} \]

\[ \text{Fancy picks, FP} = [\text{FS} (1 + 2\%)] \times \text{Fancy picks/inch} \]

\[ \text{Cut panama picks, CP} = [\text{CS} (1 + 2\%)] \times \text{Body picks/inch} \]

Total picks = TP + FP + CP

Where, TP stands for terry picks, PP stands for pile portion, FS stands for Fancy size, CS stands for cut panama size, and 2\% accounts for shrinkage of towel from loom to table.

Example 8.3:

Calculate terry picks and total picks of a bath towel when pile portion is 65.96”, body picks/1” is 37, fancy size is 3.14”, fancy picks/” are 96?

Solution:
\[ Terry \text{ picks, } TP = [PP (1 + 2\%)] \times Body \text{ picks/inch} \]

\[ Terry \text{ picks, } TP = [65.96 (1 + 2\%)] \times 37 \]

\[ Terry \text{ picks} = 7321.56 \]

\[ Fancy \text{ picks, } FP = [FS (1 + 2\%)] \times Fancy \text{ picks/inch} \]

\[ Fancy \text{ picks, } FP = [3.14 (1 + 2\%)] \times 96 \]

\[ Fancy \text{ picks} = 307.47 \]

\[ Total \text{ picks} = [TP) + (FP) + (CP)] \]

\[ Total \text{ picks} = [7321.56 + 307.46 + CP] \]

In general, the value of cut panama (CP) is 0.393”.

8.2 Relation of Pounds/dozen of towel with Gsm

8.2.1 Pounds per dozen

Pounds per dozen is term used in towel industry to express the poundage of dozen towels. In general, the orders from customer are put in the form of gsm or pounds per dozen. It can be used to determine other parameters.

\[ Pounds \text{ per dozen} = \frac{Finished \text{ weight per towel (grams)}}{37.799} \]

\[ Finished \text{ weight per towel (gms)} = lbs \text{ per dozen} \times 37.799 \]

Using above formula, the finished weight of towel (in grams) can be calculated. It can be used further to calculate GSM of towel and greige weight of towel (in grams).

\[ GSM \text{ of towel (grams)} = \frac{Finished \text{ weight} \times 1000}{l(cm) \times w(cm)} \]

\[ Greige \text{ weight per towel} = Finished \text{ weight} \times (1 + Weight \text{ loss} \%) \]

Where, \( l \) stands for total finished length and \( w \) stands for total finished width

\[ Ounces = \frac{(GSM \text{ per towel})}{28.39} \]

\[ Yard^2 = \frac{(1.0936 \times 1.0936)}{\text{(1.0936)}} \]

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Here, the constants 28.39 and 1.0936 are used to convert ounces into grams and yards into meters respectively.

### 8.2.2 Pile and Ground Ends Calculation per Towel and per Beam

\[ Greige\ width/towel = Finished\ width\ (1 + S\%) \]

Where shrinkage applied on overall width of towel is 14.4%.

\[ Pile\ ends/towel = Greige\ width/towel \times Reed\ count \]

Ground ends/towel = \[\text{[(Pile ends/towel) + (selvedge ends of both sides)]}\]

Pile beam ends = \[\text{[(Pile ends/towel } \times \text{ Number of panels) + 4 (extra ends on Beam)]}\]

Ground beam ends = \[\text{[(Ground ends/towel } \times \text{ No. of Pannels) + 16]}\]

Where, number of panels means number of towels which will be made at a time on whole width of loom and 16 ends are kept extra ends on ground beam for catch cords. In general, for reed count 30, selvage ends are 72; reed count 29.5, selvage ends are 68; reed count 27.5, selvage ends are 64; reed count 24, selvage ends are 56.

### 8.3 Pile and Ground beam space calculation

Reed space per towel means maximum space coverage of reed by pile and selvage ends.it is filled by drawing in of ends through dents of reed. And maximum reed space is calculated by multiplying reed space of towel with no. of panels (no. of towel in whole width of towel).and pile beam space is calculated by subtraction of selvage reed space from maximum reed space. While ground beam space is equivalent to maximum reed space with contraction factor of 2.032.

\[ Reed\ space/towel\ (inch) = \left( \frac{Pile\ ends/towel + Selvedge\ ends}{Reed\ count\ (inches)} \right) \]

\[ \text{Max. Reed Space} (cm) = (RS \times NP \times 2.54) + (NP \times 0.6) \]

Where, RS is reed space/towel in inches and NP is number of panel

\[ \text{Pile beam space} = [\text{Maximum Reed space} - \left( \frac{selvedge\ ends}{Reed\ count(inches)} \right) \times 2.54] \]

\[ \text{Ground beam space} = [\text{Maximum Reed space} + 2.032] \]
Reed Utilization \% = \frac{Max. Reed space \ (cm)}{Loom \ width}

**Example 8.4:**

Calculate reed space/towel in inches and maximum reed space in cm for textured rice weave towel having size 16”x28”, reed count is 27.5, pile ends per towel are 504, and selvedge ends are 64?

**Solution:**

As we know that,

\[
\text{Reed space/towel (inch)} = \frac{(\text{Pile ends/towel} + \text{Selvedeg ends})}{\text{Reed count (inches)}}
\]

\[
\text{Reed space/towel (inch)} = \frac{(504 + 64)}{27.5}
\]

\[
\text{Reed space/towel (inch)} = 20.65
\]

### 8.4 Towel weight calculations

To calculate greige weight of towel, we have to calculate weight of each portion of towel separately then by adding up weights of all weights of all portions, we get total greige weight of towel. Also from this weight of each portion, percentage of each portion of towel is calculated. In this way consumption of yarn for each portion could be estimated. Pile and ground weights are calculated by their respective ends and yarn count relationship.

\[
GW = \frac{\text{Ground ends/towel} \times \text{GEL} \times 453.6}{840 \times 36 \times \text{GC}}
\]

\[
GW \text{ with shrinkage} = GW (1 + CF\%)
\]

Where, GW is ground weight per towel (grams), GEL is ground end length (inches), GC is ground count and CF\% is contraction factor, usually taken as 9%.

Similarly, the weft and border yarn consumption is calculated by reed space, terry picks and fancy picks (FP) relationship.
\[
WW = \frac{Reed \ space \ per \ towel \ (inch) \times Terry \ picks \times 453.6}{840 \times 36 \times WC}
\]

Whereas WW is weft weight per towel (grams) and WC is weft count.

\[
FWW = \frac{Reed \ space \ per \ towel \ (inch) \times Fancy \ picks \times 453.6}{840 \times 36 \times FC}
\]

Where, FWW is fancy weft weight and FC is fancy weft count.

In the same way, Cut Panama weight (CPW) will be calculated as:

\[
CPW = \frac{Cut \ Panama \ (inch) \times Pile \ ends \ per \ towel \times 453.6}{840 \times 36 \times Pile \ Count}
\]

\[
PWTP \ (grams) = Total \ greige \ weight \ of \ towel - (GW + WW + FWW + CPW)
\]

Where PWTP stands for Pile weight in the terry portion per towel.

Now, percentage of each portion will be calculated separately from their respective weights.

\[
Pile \% = \left( \frac{PWTP}{Greige \ weight \ per \ towel} \right)
\]

Similarly, ground, weft and border weft percentages will be calculated and consumption of each yarn will be estimated. These percentages are helpful to further yarn demand of each yarn.

### 8.5 Towel Construction Calculation

Five parameters are used to calculate construction of towel including pile height by single (PH/1), pile height by ten (PH/10), pile ratio per cm, ends per inch(epi), picks per inch (ppi) and terry loop per square inches. Pile ratio means how much pile yarn will be consumed per cm of ground yarn.

\[
Pile \ Ratio/cm = \frac{Pile \ wt. \ in \ Terry \ portion \ per \ towel \ (gms) \times Pile \ count \times 840 \times 36}{(Pile \ ends/towel \times Pile \ Portion(inches)) \times 453.6}
\]

Pile height by 10 (PH/10) is average per height of 10 loops and Pile height by single, while (PH/1) is the pile height of single loop.
\[
\text{Pile height by 10 (PH/10) in mm} = \left( \frac{\text{Pile Ratio} \times 25.4}{\text{Body picks per cm}} \right) \times 2
\]

\[
\text{Terry loop per square inches (Cover Factor)} = \frac{\text{EPI}}{4} \times \frac{\text{PPI}}{3}
\]

### 8.5.1 Towel Production Calculations

Some commonly used relations for towel production calculation are:

\[
\text{Daily Production (pcs)} = \frac{(\text{RPM} \times 60 \times 24 \times \text{Running pcs/border} \times N)}{\text{Total Picks}} \times \text{E\%}
\]

Where, \( N \) is the number of looms.

\[
\text{Daily finish Production (lbs)} = \frac{\text{Daily production (pcs)} \times \text{Finish weight/towel (gms)}}{453.6}
\]

\[
\text{Monthly Production (pcs)} = \text{Daily Production} \times \text{Working days}
\]

\[
\text{Monthly finish production (lbs)} = \text{Daily finish production (lbs)} \times \text{Working days}
\]

\[
\text{Monthly Greige production (lbs.)} = \frac{\text{Greige wt. per towel} \times \text{Daily Production (pcs)}}{\text{Working days} \times 453.6}
\]

### 8.5.2 Pile and Ground Beam length (Set length) Calculation

The set length calculations involve the determination of pile and the ground beam length. Firstly, we have to calculate the pile weight (lbs) of towel and then using the relation between pile weight and pile beam ends, pile beam length is calculated.

\[
\text{Total Pieces} = \text{Pieces required} \times (1 + B\ Grade\%) \]

The finished weight calculations have already been discussed in the earlier sections. In general, there is some weight loss in case of yarn dyed towel. So, the greige weight can be calculated as:

\[
\text{Greige weight (grams)} = \text{Finish weight} \times (1 + \text{Weight loss\%})
\]

Using the value of this greige weight, ordered weight (weight of ordered quantity) is calculated using the following relation:
Ordered weight (lbs) = \frac{\text{Total pieces} \times \text{Greige weight (grams)}}{453.6}

Ordered weight (lbs) = \text{Ordered weight (lbs)} (1 + M\%)

Where M is margin applied on total ordered quantity, and is taken 3\% normally. This ordered weight is multiplied with the pile\% and ground \% to get the pile and ground weight in lbs.

\text{Pile weight (lbs)} = \text{Pile \%} \times \text{Ordered weight (lbs)}

\text{Ground weight (lbs)} = \text{Ground \%} \times \text{Ordered weight (lbs)}

These pile and ground weights are used to further calculate pile and ground beam length (set length).

\text{Pile Beam length (meter)} = \frac{(\text{Pile wt. (lbs)} \times \text{Pile count} \times 768.1)}{\text{Pile beam ends}}

\text{Ground Beam length (meter)} = \frac{(\text{Ground wt. (lbs)} \times \text{Ground count} \times 768.1)}{\text{Ground beam ends}}

Example 8.5:

Calculate pile beam length (set length) and ground beam length (set length) in meters from given ordered quantity using below data.

Weight loss for dyed yarn = 7\%

Ordered quantity in pieces = 37400

Lbs. / dzn (poundage per dozen) = 13.25

Pile \% = 50\% \quad \text{Ground \%} = 18\%

Pile Beam ends = 2660 \quad \text{Ground Beam ends} = 3216

Pile Count = 20/2 \quad \text{Ground Count} = 10

Solution:

If we consider 5\% as B grade pieces, then the total number of pieces required are:
Total Pieces = \[37400 \times \left(1 + \frac{5}{100}\right) = 39270\]

Finish weight (grams) = \[13.25 \times 37.799 = 500.83\] grams

Greige weight (grams) = \[500.83 \times \left(1 + \frac{7}{100}\right) = 535.89\] grams

Ordered weight (lbs) = \[
\frac{39270 \times 535.89}{453.6} = 46395\] lbs

Applying a margin of 3% on the ordered weight, we get

Ordered weight in lbs = \((46395.21(1 + 0.03) = 47787.1\) lbs

Now, this weight is used to calculate the individual pile and ground weights.

Pile wt. (lbs) = \((47787.1 \times 0.5) = 23893.53\) lbs

Ground wt. (lbs) = \((47787.0663 \times 0.018) = 8601.67\) lbs

The set lengths of pile and ground beam are calculated as:

\[
Pile Beam length (meter) = \frac{23893.53 \times 10 \times 768.1}{2660}
\]

Pile Beam length = 68994.83 meter

\[
Ground Beam length (meter) = \frac{8601.67 \times 10 \times 768.1}{3216}
\]

Ground Beam length = 20453.98 meter

8.5.3 Direct warping calculations
In case of any simple terry towel, planned on direct warping machine, following inputs are required: number of cones, cone weight and number of bags for each pile and ground yarn. The warping machine creel capacity and number of beams are also taken into consideration

\[
Number\ of\ cones = \frac{Pile\ or\ ground\ beam\ ends}{No.\ of\ beams}
\]

\[
Cone\ length\ (m) = (Pile\ or\ ground\ beam\ length\ +\ sizing\ waste) \times \frac{Number\ of\ beams}{No.\ of\ beams}
\]
\[ \text{Cone wt. (pile or ground)} = \frac{\text{Cone length}}{\text{Count} \times 768.1} \]

\[ \text{Cone wt. with left over} = \text{Cone wt. (pile or ground)} + \frac{\text{Left over on cone}}{\text{Count} \times 768.1} \]

Usually left over taken on each cone is 800 meter.

Total no. of cones = (Cones \times Number of creels) + 1 (extra cone)

Please note that number of creels will be 1 if cones less than and equal to 6.25 lbs. but if cone weight is greater than 6.25 lbs, we have to increase number of creels to 2, 3 or more, depending upon cone weight.

Total wt. (lbs.) = (Total no. of cones \times cone wt. with left over)

\[ \text{No. of bags} = \frac{\text{Total wt. (lbs.)}}{100} \]

Same Calculation will be performed for yarn demand of ground yarn.

Example 8.6:

Raise yarn demand of pile and ground from given pile beams and ground beam ends and pile beam length, how many no of bags will be required for both pile and ground count?

Pile beam ends = 2660

Ground beam ends = 3216

Pile beam length = 2940.5 meter

Pile Count = 20/2

Ground Count = 10

Solution:

No. of cones?

Cones wt. for pile yarn?
Cones wt. for ground yarn?

No. of pile bags?

If the number of beams are 6, then number of cones are:

Number of cones = \( \frac{2660}{6} = 443.33 = 444 \) cones required

Cone length (pile or ground) = \((2905 \text{ m} + 100) \times 6 = 18030 \text{ mtr.}\)

\[
\text{Cone wt. (pile or ground)} = \frac{18030}{10 \times 768.1} = 2.348 \text{ lbs}
\]

\[
\text{Cone wt. with left over} = 2.348 + \frac{800}{10 \times 768.1} = 2.453 \text{ lbs}
\]

The number of creels will be one, as cone wt. less than 6 lbs.

Total no. of cones = 444 x 1 + 1 = 445 total cones required

Total wt. (lbs.) = 445 x 2.453 = 1091.21 lbs.

No. of bags = \( \frac{1091.21}{100} = 10.92 \) bags of pile required

Same Calculation will be performed for yarn demand of ground yarn.

8.6 Ball warping

Ball warping is the process in which warping is performed in rope form onto balls and warp beam is prepared after subsequent process. This type of warping is suitable for denim fabric manufacturing that involves rope dyeing process. Ball warping is a two stage process, initially the warp yarns are wound in rope form on cheese like structure. Ball is wound on special wooden core called “log” and rope dyeing is performed.

The ball warping calculations are somehow similar to the direct warping calculations as discussed in the chapter 3. The warping is usually planned with single or double creel. The length of yarn on warp beam is decided taking into consideration the shrinkage % and the rejection % of the yarn and fabric. In general for denim fabric, there is 10% allowance for the rejection and 15-20% for the shrinkage of fabric, i.e. to produce 10,000 meter denim fabric, the warping is usually 12,500-13,000 meters. The calculation will be clarified with the following example.
Example 8.7:

To produce a denim fabric with 10/s yarn having 67 ends/inch and 63” width, calculate the length of warp required.

Solution:

The length of warp required will be calculated as:

Total ends = 67×63 = 4221

Number of logs = 12

Number of ends/log = 4221/12 = 351.75

So, 9 logs will have 352 ends and 3 logs will be with 351 ends. The plan for one creel will be as follows:

Number of cones per bag = 16

Cone weight = 100 / 16 = 6.25 lbs

Length of yarn on one cone = 6.25 × 10 × 768.1 = 48006 m

Length taken percentage is usually 99% because of variation in yarn length among different cones, to avoid length short problem.

Length taken from cone = 48006 × 0.99 = 47526 m

Warp length / log = length taken from one cone / Number of logs

Warp length / log = 47526 / 12 = 3960.5 m

The yarn requirement can be calculated as:

Number of bags required = Number of ends on log / Number of cones in bag

Number of bags required = 352 / 16 = 22 bags
8.7 Filament warping

The filament warping process is generally performed on direct warping machine with H type swivel frame creel (also called rotating frame creel). This type of creel was designed as a variation of mobile creel to enable the creeling of heavy weight cones, which cannot be pinned on trolleys. Each bobbin holder is double-sided: the threads are unwound from outer side, while a new series of bobbins is creeled on inner side.

In general, the preparation of weaver’s beam for filament yarn is a three step process namely warping, sizing and re-beaming. Initially a single beam of warp is prepared on warping. This single beam is sized and split into beams of small warp length on sizing beams. These sized beams are loaded on the creel of re-beaming machine and then combined to get a single weavers beam. The following example will help to clarify the process of filament sizing and its calculations.

Problem 8.8 Perform filament sizing calculations for the below quality.

Quality: 167 dtex × 16 / 112 × 60, 63”

Solution:

Total ends = 112×63 = 7056

Number of sized beams = 12

Number of ends/sized beam = 7056/12 = 588

Cheese weight = 6.25 lbs

Warp linear density = 167/10 = 16.7 tex

Length of yarn on one cheese = (Weight in grams) × 1000) / Tex count

Length of yarn on one cheese = (6.25 × 453.6) × 1000) / 16.7 = 169761 m

Length taken percentage is usually 99% because of variation in yarn length among different yarn packages, to avoid length short problem.

Length taken from cone = 169761 × 0.99 = 168064 m

Now, this length of yarn can be used to prepare either one, two, or more number of warp beams. Each warp beam will be considered as a separate set, and will be run independent of each
other. The creel capacity will be equal to the number of ends required on a single sized beam, i.e. 588. If number of warp beams is two, then:

\[
\text{Warp beam length} = \frac{\text{length taken from one cone}}{\text{Number of beams}}
\]

\[
\text{Warp beam length} = \frac{168064}{2} = 84032 \text{ m}
\]

\[
\text{Sized beam length} = \frac{\text{Warp beam length}}{\text{Number of sized beams}}
\]

\[
\text{Sized beam length} = \frac{84032}{12} = 7003 \text{ m (approx.)}
\]

These 12 sized beams will then be combined on the beaming machine to give a weaver’s beam with the required number of ends having 7003 meters length.

### 8.8 Sample warping and sizing

Sample warping machine is a modified form of conventional warping machines, developed for sampling purposes, especially the ones utilizing coloured yarns or yarns of more than one count/type. The warping process is composed of several operations which wind up a limited thread length and place them on the warping width with several bands of different colours to get the colours variant of the fabric. The objectives of sample warping are:

- Preparation of samples for research
- To get the variant colours in the fabric
- Product from a limited amount of yarn
- To save time by working fast
- Reduction in labor cost

The sample warping machine produces the end product to be used directly on the loom for weaving. Therefore, the yarn used for warping must be sized to avoid excessive breakages and associated problems on loom. This is achieved using the single end sizing machine. The yarn from cone is passed through a coating bath containing size liquor. It is then dried by passing through hot air chamber. The wrapping reel is used in the drying chamber to accommodate maximum amount of yarn and to enhance the drying time for proper drying.

The following example will elaborate the calculations for the sampling machines.

**Example 8.9:**

*Suppose a yarn dyed fabric is to be produced in the following quality with three colours according to a given colour repeat. Perform the sampling calculations.*
Quality: 30×30/80×62, 63”

Colour repeat = 37 (1G + 1W) + 13 (2B + 2W) = 126 ends

Where, G is green, W is white and B is brown.

Solution:

Total ends = 80×63 = 5040

The colours of each ends required to produce fabric are calculated as:

Colours in one repeat = 37 G, 63 W, 26 B

Number of repeats in fabric = 5040/126 = 40

Number of green yarns in fabric = 37 × 40 = 1480 ends

Number of white yarns in fabric = 63 × 40 = 2520 ends

Number of brown yarns in fabric = 26 × 40 = 1040 ends

Now, the length of each yarn required depends on the diameter of drum in sample warper. The weaver’s beam prepared usually accommodates 2.5 m length of warp sheet, according to the diameter of warper drum. Hence, the yarn required can be calculated as, if we account for 5% yarn wastages:

Length of a yarn = Number of ends × Warp length × (1 + wastage %)

Length of green yarn = 1480 × 2.5 × (1 + 5%) = 3885 m

Length of white yarn = 2520 × 2.5 × (1 + 5%) = 6615 m

Length of brown yarn = 1040 × 2.5 × (1 + 5%) = 2730 m

Now, this length of yarn is required on the cones. It is achieved during sizing process. These machines have a digital length counter, and stops the machine as soon as the required length is achieved.

8.9 Exercise
Problem 8.1 Calculate greige width/towel in inches for Sainsbury yarn dyed towel having size 70x130 cm, pile ends/towel and pile beam ends, reed count is 30?
Problem 8.2 Calculate greige width/towel in inches for Sainsbury yarn dyed towel having 100x150 cm, Ground ends/towel and Ground beam ends, reed count is 29.5?

Problem 8.3: Calculate Total picks for yarn dyed towel having size 50x90 cm with 500 gsm, fancy size is 3.14”, fancy picks per inch is 120, body picks per inch is 41 and cut panama size is 0.393”?

Problem 8.4: Calculate pile cone length from given cone weight 1.958 lbs and pile count is 20/2 cd 8~9 TPI?

Problem 8.5: Calculate pile to pile length and pile portion for kitan Espirit All Terry beach towel having size 100x180 cm and having end hem 1.5 cm satin?

Problem 8.6: Calculate Pile beam space having pile beam ends 2480, reed count is 27.5”, number of panels are 2, maximum reed space is 241.1 cm?

Problem 8.7: Calculate Ground beam space having Ground beam ends 2748, reed count is 27.5”, number of panels are 2, maximum reed space is 241.1 cm?

Problem 8.8: Calculate pile and ground set length having pile weight in lbs is 5135, pile beam ends and ground beam ends are 2484 and 2748, pile and ground counts are 20/2 cd s twist and 10/1 cd respectively?

Problem 8.9: Perform the sample warping and sizing calculations for the yarn dyed fabric having following quality with four colours according to a given colour repeat.

Quality: 32×21/133×80, 63”

Colour repeat = 12 (1G + 1W) + 13 (2B + 2Y)

Where, G is green, W is white and B is brown and Y is yellow.

Problem 8.10: Perform the sample warping and sizing calculations for the yarn dyed fabric having following quality with three colours according to a given colour repeat.

Quality: 20×20/100×60, 65”
Colour repeat = 20 (2R + 2W) + 20 (2B + 2W)

Where, R is red, W is white and B is blue.

Problem 8.11: Perform filament sizing calculations for the below quality. Where available beaming capacity is 10, and cheese weight is 4.25 Kgs.

Quality: 250 dtex × 20 / 96 × 56, 65”

Problem 8.12: A fabric is to be produced from 175 denier of polyester yarn. The warp density is 96 ends/inch. How the sizing calculation of this filament yarn will be performed if available beaming capacity is 8, and cheese weight is 5.15 Kgs.
9. Knitting

Knitting is the second largest and most growing technique of fabric manufacturing in which yarns are interloped to make thick yet flexible and elastic fabric. Knitting is fabric formation technique in which the yarn is bent into loops and those loops are interconnected to form fabric. Knitting can be defined in simple words as the interloping of yarn. The bending of yarn provides better stretch, comfort and shape retention properties. However, they tend to be less durable as compared to the woven fabric.

9.1 Fabric Analysis

Fabric Analysis is performed to check the parameters of the fabric. The different parameters investigated in a fabric include stitch length, course and wale spacing, stitch density, areal density, etc. These parameters of fabric are essential to reconstruct the fabric, and are also used for quality assurance of produced fabric.

The stitch length of knitted fabric is an important parameter to engineer the properties of the knitted fabric. All the knitted parameters like course and wale spacing, stitch density and fabric areal density are effected by the stitch length. The following formulas are used to calculated the fabric parameters

\[
\text{Stitch length (cm)} = \frac{\text{Length of yarn for } n \text{ loops(cm)}}{\text{Number of loops, } n}
\]

The fabric density depends on the number of stitches per unit area. It is the number of courses per inch and number of wales per inch.

\[
\text{Courses/inch (CPI)} = \frac{\text{Number of courses}}{\text{Width of fabric (inches)}}
\]
Wales/inch (WPI) = \( \frac{\text{Number of wales}}{\text{Length of fabric (inches)}} \)

Stitch density (stitches/inch²) = \( \frac{\text{Number of stitches}}{\text{Area of fabric (inch}^2\text{)}} \)

The fabric areal density is expressed in terms of weight per unit area. The most commonly used terms are grams per square meter (GSM) and ounces per square yard (OSY).

Areal density, GSM (gram/m²) = \( \frac{\text{Fabric weight (gram)}}{\text{Area of fabric (meter}^2\text{)}} \)

Areal density, GSM (gram/m²) = \( \frac{\text{Fabric weight (gram)} \times 10000}{\text{Area of fabric (cm}^2\text{)}} \)

Areal density, OSY (oz/yard²) = \( \frac{\text{Fabric weight (ounces)}}{\text{Area of fabric (yards}^2\text{)}} \)

Areal density, GSM = 33.906 \( \times \) Areal density, OSY

## 9.2 Optimum knitting calculation

The selection of exact knitting parameters on machines for different qualities of fabric is essential. The optimum knitting parameters help to maintain the uniform quality in fabric. There are few knitting parameters like tightness factor, machine gauge, input tension, stitch length and course length that should be decided before knitting. The tightness factor gives the idea of tightness and looseness of the fabric.

The selection of optimum loop length according to the yarn linear density is important to decide to get the required tightness in the fabric. Normally the tightness range for plain jersey fabric is 13 to 19; while 15 is considered as the optimum tightness factor. The second factor is the selection of gauge of the machine, and depends on the yarn linear density. The input tension is an important factor, helping in the smooth running of yarn on knitting machine. The length of yarn given to the machine at each feeder is called course length. This is important factor to get the required stitch length of the fabric. The following formulas are used to calculate the optimum condition of the knitting.

\[ \text{Tightness factor, } k = \frac{\sqrt{\text{tex}}}{l(\text{cm})} \]

\[ \text{Loop Length, } l(\text{cm}) = \frac{\sqrt{\text{tex}}}{K} \]
Machine gauge, G determines the yarn count that can be run on the machine. It is calculated as:

\[
Yarn\ tex = \left(\frac{100}{G}\right)^2
\]

\[
Worsted\ count = \frac{G^2}{10}
\]

\[
Input\ tension\ (gram) = 0.1 \times tex
\]

\[
Course\ Length\ (cm) = Loop\ Length \times Number\ of\ needles\ per\ course
\]

**Example 9.1:**

*For 30/1 Nec cotton yarn, calculate the optimum knitting condition, if fabric is knitted on 30 inch diameter single jersey machine running at the speed of 25 rpm.*

**Solution:**

For optimum gauge, following relation can be used

\[
Yarn\ tex = \left(\frac{100}{G}\right)^2
\]

\[
30Nec = 19.6\ tex
\]

\[
G = \frac{100}{\sqrt{tex}} = \frac{100}{\sqrt{19.6}} = 22.5
\]

So the optimum gauge is 22

\[
Loop\ Length\ (mm) = \frac{\sqrt{tex}}{K}
\]

Consider the optimum tightness values is 1.5.

\[
Loop\ Length\ (mm) = \frac{\sqrt{19.6}}{1.5} = 2.95\ mm
\]

\[
Input\ tension = 0.1 \times tex = 0.1 \times 19.6 = 1.96\ gram
\]

\[
Number\ of\ needles\ on\ machine = \pi \times D \times E = 3.14 \times 30 \times 22 = 2072\ needle
\]
Course length = loop length x number of needle = 2.95 mm × 2072 = 6112 mm

9.3 Yarn Composition

The composition of the final fabric is an important factor to calculate if the fabric is formed by the different composition of yarn. The selection of right percentage of blend yarn is crucial when fabric is composed of 2 or 3 different composition of yarns. The composition of overall fabric can be calculated from the percentage of each yarn participated in fabric formation. The following formula can be used for this purpose.

\[ FX_A\% = (FW_A\%) \times (X_A\%) \times 100 \]

Where,

- \( FX_A\% \) is the percentage of X material in fabric contributed by yarn A
- \( FW_A\% \) is the fabric weight percentage contributed by yarn A
- \( X_A\% \) is the percentage of X material in yarn A

In the above equations X may be any material like cotton, polyester, wool, etc., while A is the yarn type like face or loop yarn etc.

Similarly the same formula can be used to calculate the percentage of X material in the fabric contributed by yarn B and C (depending on the number of yarns). The overall percentage of X material in fabric is the sum of all these values.

Overall percentage of X material in fabric = \( FX_A + FX_B + FX_C \)

In the same way, percentage of material Y and Z, in fabric will be:

- Overall percentage of Y material in fabric = \( FY_A + FY_B + FY_C \)
- Overall percentage of Z material in fabric = \( FZ_A + FZ_B + FZ_C \)

Example 9.2:

Calculate the composition of the 2 thread terry fabric in which one thread is use on knit side and other on the loop side with the percentage of 60 and 40 respectively. The composition of knit 80/20 CVC and loop yarn is 50/50 PC.
Solution:

Knit thread is composed of 80 percent cotton and 20 percent polyester.

Loop thread is composed of 50 percent cotton and 50 percent polyester.

There are two main materials, one is cotton and other is polyester.

\[
\text{Cotton } \% \text{ in fabric from knit yarn} = \left( \frac{60}{100} \times \frac{80}{100} \right) \times 100 = 48 \%
\]

Similarly cotton percentage in fabric from loop yarn can be calculated as:

\[
\text{Cotton percentage in fabric from loop yarn} = \left( \frac{40}{100} \times \frac{50}{100} \right) \times 100 = 20 \%
\]

Overall cotton \% in fabric = 48% + 20% = 68%

Polyester \% in fabric = 100 – Cotton \% 

Polyester \% in fabric = 100 – 68 = 32 \%

The overall fabric composition is 68/32 CVC.

9.4 Yarn requirement

Generally, in knitting, the required fabric order is placed weight wise. The equal amount of yarn in weight are required to produce the fabric. In case of fabric produced with single type of yarn like Single jersey, Rib, interlock and most of their derivatives, required yarn weight will be:

\[
\text{Yarn required} = \text{Required fabric weight} \times (1 + \text{Wastage } \%)
\]

The wastages during knitted fabric production vary from unit to unit, and normally range from 2-5%.

9.4.1 Terry fabrics (two end and three end)

When the fabric is produced from two or more different kinds of yarns, then we need to calculate the percentage of each yarn in the fabric. The requirement of each yarn will be according to the percentage of the total required weight of the fabric.
In case of 2 end terry fabric, the fabric is composed of two different yarn, one is a knit yarn and other is pile or loop yarn. The requirement of each yarn can be calculated as follows.

\[
KY_r = KY_\% \times F_w \\
TKY_r = KY_r \times (1 + W_\%) \\
LY_r = LY_\% \times F_w \\
TLY_r = LY_r \times (1 + W_\%)
\]

Where:

\(KY_r\) = Knit yarn requirement  \\
\(KY_\%\) = Knit yarn percentage  \\
\(F_w\) = Fabric Weight  \\
\(TKY_r\) = Total knit yarn requirement  \\
\(W_\%\) = Wastage percentage  \\
\(LY_r\) = Loop yarn requirement  \\
\(LY_\%\) = Loop yarn Percentage  \\
\(TLY_r\) = Total loop yarn requirement

The three end terry fabric has three different yarns at different knitting position. The first two types of knitting position are discussed in the previous section. The third position is binding-in. the following formula can be used to calculate the yarn requirement for binding-in yarn.

\[
BY_r = BY_\% \times F_w \\
TBY_r = BY_r(1 + W_\%)
\]

\(BY_r\) = Binding yarn requirement  \\
\(BY_\%\) = Binding yarn Percentage  \\
\(TBY_r\) = Total Binding yarn requirement
**Example 9.3:**

It is required to produce 2000 kg of a terry fabric composed of three thread used at different knitting position (knit, binding and loop). The percentage of yarn at different position is 50, 35 and 15 respectively. Calculate the yarn requirement for each position with additional percentage of 2 %.

**Solution:**

There are three different yarn used at different knitting position in 3 thread fabric.

To calculate the yarn requirement for each yarn. We have the following relation.

\[
KY_r = KY_\% \times F_w = \frac{50}{100} \times 2000 = 1000 \, kgs
\]

\[
TKY_r = KY_r + W_\% \times KY_r = 1000 + \frac{2}{100} \times 1000 = 1020 \, Kgs
\]

\[
BY_r = BY_\% \times F_w = \frac{35}{100} \times 200 = 700 \, Kgs
\]

\[
TBY_r = BY_r + W_\% \times BY_r = 700 + \frac{2}{100} \times 700 = 714 \, Kgs
\]

\[
LY_r = LY_\% \times F_w = \frac{15}{100} \times 2000 = 300 \, Kgs
\]

\[
TLY_r = LY_r + W_\% \times LY_r = 300 + \frac{2}{100} \times 300 = 306 \, Kgs
\]

**9.4.2 Jersey Lycra fabric**

The single jersey elastane fabric is composed of two yarns; one is the main yarn while other is pleated yarn. In this case, the main yarn consumption is calculated as:

\[
My_r = My_\% \times F_w
\]

\[
TMy_r = My_r \times (1 + W_\%)
\]

\[
My_r = \text{Main yarn Requirement}
\]
9.4.3 Striper fabric

For striper fabric, the percentage of each stripe should be known. The percentage of each stripe can be calculated from the number of courses of each color stripe in the fabric, if there are three color in the stripe repeat then percentage of each stripe can be calculated as follows.

\[
\text{Color (X)}\% = \frac{\text{Number of courses of (X) color}}{\text{Total number of courses}} \times 100
\]

X may be any color e.g. red, green, blue, etc.

The yarn requirement of each color can be calculated as follows:

\[
\text{Color (X) yarn requirement} = \% \text{ of Color X} \times F_w
\]

Total color X yarn requirement = \(\text{Color X yarn requirement} \times (1 + W\%)\)

\(F_w = \text{Fabric weight}\)

\(W\% = \text{wastage percentage}\)

**Example 9.4:**

*Calculate the yarn requirement of each colour of given striped fabric. The total required fabric is 2000 kgs. Consider the wastage percentage of each color is 2 %. The stripe details are as follows. A = 30 courses, B = 16 courses, C = 40 courses*

**Solution:**

First we need to calculate the ratio of each colour yarn in the fabric.

\[Total \text{ course } = 30 + 16 + 40 = 86\]
\[
\text{Ratio of A colour} = \frac{30}{86} = 0.348 \\
\text{Ratio of B colour} = \frac{16}{40} = 0.186 \\
\text{Ratio of C colour} = \frac{40}{86} = 0.465 \\
\]

Now multiply the ratio of each colour yarn to the total required weight of fabric.

\[
\text{Colour A yarn requirement} = 0.348 \times 2000 = 696 \text{ Kgs} \\
\text{Colour A yarn with wastages} = 696 + 696 \left( \frac{2}{100} \right) = 709.92 \text{ Kgs} \\
\text{Colour B yarn requirement} = 0.186 \times 2000 = 372 \text{ Kgs} \\
\text{Colour B yarn with wastages} = 372 + 372 \left( \frac{2}{100} \right) = 379.44 \text{ Kgs} \\
\text{Colour C yarn requirement} = 0.465 \times 2000 = 930 \text{ Kgs} \\
\text{Colour A yarn with wastages} = 930 + 930 \left( \frac{2}{100} \right) = 948.6 \text{ Kgs} \\
\]

### 9.5 Knitted Fabric Dimensions

#### 9.5.1 Areal density, GSM

The areal density of plain single knit fabric can be predicted at three relaxation stages namely dry, wet and fully relaxed.

\[
\text{Area density (GSM)} = \frac{S \times L \times \text{tex}}{100} \\
S = \text{Stitch density (cm2)} \\
L = \text{Stitch length (mm)} \\
\text{tex} = \text{yarn count in tex}
\]
9.5.2 Width
The width is an important parameter of the knitted fabric. For body size fabric, width tolerance is very short. So the right estimation of the fabric is important.

\[
\text{Width of fabric in inches} = \frac{N}{WPI}
\]

\(N = \text{Number of needle}\)

\(WPI = \text{wales per inch}\)

9.6 Cam and needle requirement
For the cam system, on circular knitting machine, the cam and needle requirement are being checked. The requirement was based on the no of feeder, cams, needle repeat and active tracks on the machine. This calculation was made for the designs of Single jersey, rib, interlock and its derivatives.

9.6.1 For Single knit and its derivatives
i. Plain jersey:
In case of plain jersey fabric, the design consists of all the knit stitches. This design can be produced using minimum one track of the machine. So, the knit cams required with using one track are calculated as:

\[
\text{Knit cams required} = T_{ac} \times F
\]

\(T_{ac} = \text{Active tracks on cylinder}\)

\(F = \text{Feeders on machine}\)

\(\text{Needle required for one track} = \pi D E\)

\(D = \text{Dia of the cylinder in inches}\)

\(E = \text{gauge (needles per inch)}\)

If there are two tracks are used and needles placed one by one for each track then half needle are used for “A” track and half are used “B” track.
Similarly for 3 and 4 tracks, the needle will be calculated.

ii. **Plain Pique:**

The design repeat of plain pique consists of 2 feeders. Working position of knit and tuck is at alternative positions:

\[
\text{Knit cams required for} = \frac{T_{ac} \times F}{2}
\]

\[
\text{Tuck cams required} = \frac{T_{ac} \times F}{2}
\]

9.6.2 **For double knit structure**

The total cams required are calculated both for Dial and Cylinder.

\[
\text{Cam required an Cylinder} = T_{ac} \times F
\]

\[
\text{Cam required on Dial} = T_{ad} \times F
\]

\[
T_{ad} = \text{Active tracks on dial}
\]

If more than one track are used, then cams for each track will be calculated according to the design of the rib and its derivative.

The required needle are calculated according the diameter and gauge of the machine for both dial and cylinder.

\[
\text{Needle required for Cylinder} = \pi D E
\]

\[
\text{Needle required for Dial} = \pi D E
\]

If there are two or more tracks are used, then needles for each type are calculated according to the needle repeat.

**Example 9.5:**

*Calculate the cam the needle requirement of given lapique design. The plain knitted circular machine specifications are given as: gauge = 20, diameter = 30 inches, number of feeders = 90*
Solution:

The design repeat consists of 2 wales and 4 courses. Total feeders on machine are 90. Total feeders that can be used for this design is 88 because 88 is a multiple of 4 minimum 4 feeders are required to produce this design on machine. The total repeat of feeders are 22. The remaining two feeders will be inactive in this case.

The design courses have two different types of stitches. So there is a requirement to produce this design on two tracks.

\[ Total \text{cams required on machine} = T_{ac} \times F = 2 \times 90 = 180 \]

\[ Knit \text{cams required in a repeat} = 6 \]

\[ Total \text{knit cans required for 88 feeders} = 6 \times 22 = 132 \]

\[ Miss \text{cams required in a repeat} = 2 \]

\[ Total \text{miss cans required for 88 feeders} = 2 \times 22 = 44 \]

\[ Miss \text{cams required for remaining two feeders} = 4 \]

\[ Total \text{miss cans required} = 44 + 4 = 48 \]

Needle requirement:

\[ Total \text{needles on machine} = \pi \times D \times E = 3.14 \times 20 \times 30 = 1884 \]

Because 2 tracks are used, so two types of needle will be used. The needle repeat will be in alternate manner. Say “A” is a one type of needle and “B” is a second type of needle.

\[ Total \text{type “A” needle required} = \frac{N}{2} = \frac{1884}{2} = 942 \]
Total type “B” needle required \( = \frac{N}{2} = \frac{1884}{2} = 942 \)

### 9.7 Production calculations of Circular knitting Machine

The Production of the circular knitting machine is commonly expressed in terms of length (yards, meters) and weight (Kgs, Lbs.) in specific times. It depends on a number of factors; mainly machine speed, number of feeders, fabric parameters, etc. The production of circular knitting machine in Yards/hour can be determined from the following formula.

\[
P \text{(yds./t)} = \frac{s \times f \times t \times 60 \times F}{CPI \times 36} \times E_\% \]

\[
P \text{(meters/t)} = \frac{s \times f \times 60 \times F}{CPI \times 39.36} \times E_\%
\]

Where,

- \( P \) = Production
- \( t \) = time (hours)
- \( s \) = Machine speed (RPM)
- \( f \) = No of feeders
- \( F \) = fabric length
- \( CPI \) = Courses per inch
- \( E_\% \) = Efficiency Percentage

The fabric production in weight per unit time can be calculated from the following formula

\[
P \text{(lbs./t)} = \frac{s \times f \times t \times N \times l \times 60 \times F \times C}{2.54 \times 36 \times 840 \times N_e} \times E_\%
\]

- \( N \) = number of needles
- \( l \) = Stitch length (cm)
- \( C \) = fabric constant
\[ Ne = English \ count \]

\[
\text{Fabric weight} / \text{linear yards (lbs)} = \frac{N \times l \times CPI \times 36}{2.54 \times 36 \times 840 \times Nec}
\]

\[
\text{Fabric weight} / \text{linear meters (lbs)} = \frac{N \times \text{stitch length} \times \text{courses per inch} \times 39.36}{36 \times 2.54 \times 840 \times Nec}
\]

**Example 9.5:**

Calculate the production in pound per hour and yards per shift if single jersey fabric is knitted with following parameters, Feeder=20, RPM=25, S.L= 0.32 cm, Number of needle =1200, CPI=36 yarn, Count=18/1 Ne, efficiency= 84 %.(Consider shift = 12h)

**Solution:**

First calculate the production in pound per hour.

Where:

\[ S = 25 \ \text{rpm} \]

\[ f = 20 \]

\[ l = 0.32 \ \text{cm} \]

\[ t = 1 \]

\[ F = 1 \ (\text{for structure in which one feeder makes one complete course}) \]

\[ C = 1 \ (\text{for single knit structure}) \]

\[ N = 1200 \]

Count = 18/1 Ne, \[ E_x = 84\% \]

\[
P (\text{lbs/t}) = \frac{s \times f \times t \times N \times l \times 60 \times F \times C}{2.54 \times 36 \times 840 \times N_e} \times E_x
\]

\[
P (\text{lbs/t}) = \frac{24 \times 20 \times 1 \times 1200 \times 0.32 \times 60 \times 1 \times 1 \times 0.84}{2.54 \times 36 \times 840 \times 18}
\]
\[ P \text{ (lbs/t)} = 6.71 \text{ lb/hr} \]

To calculate the production in yards/shift, following relation will be used.

Where, CPI = 36 and Time = 12 hours

\[ P(yards/t) = \frac{s \times f \times t \times 60 \times F}{CPI \times 36} \times E\% \]

\[ P(yards/t) = \frac{24 \times 20 \times 12 \times 60 \times 1 \times 0.84}{36 \times 36} \]

\[ P \text{ (yds./t)} = 224 \text{ yards/shift} \]

### 9.8 Warp knitting calculations

Warp knitting may be defined as the loop formation process along the warp direction of the fabric. The simultaneous sheet of yarn is provided to machine along the warp direction for loop formation process. The sheets of yarn are supplied from warp beam like in weaving. Each warp end is provided to the each individual needle. The same yarn runs along the warp direction and needle draws the new loop yarn through the old loop that was formed by another yarn in previous knitting cycle.

### 9.8.1 Production calculations

The production of warp knitted fabric can be calculated length and weight wise over specific time. The following formula can be used to calculate the warp knitting machine production

\[ P_{\text{rmph}} = \frac{M_s \times 60 \times E\%}{CPI \times 39.36} \]

\[ P_{\text{ryph}} = \frac{M_s \times 60 \times E\%}{CPI \times 36} \]

\[ P_{\text{smph}} = P_{\text{rmph}} \times F_{\text{width(m)}} \]

\[ P_{\text{syph}} = P_{\text{rmph}} \times F_{\text{width(yrd.)}} \]

\[ P_{\text{gph}} = P_{\text{smph}} \times F_{\text{w(gsm)}} \]
\[ P_{ozph} = P_{syph} \times F_{w(ozsy)} \]

Where:

\[ P_{rmph} = \text{Production in running meter per hour} \]
\[ P_{ryph} = \text{production in running yards per hour} \]
\[ P_{smph} = \text{production in square meters per hour} \]
\[ P_{syph} = \text{production in square yards per hour} \]
\[ P_{gph} = \text{production in grams per hours} \]
\[ P_{ozph} = \text{production in ounces per hours} \]
\[ M_s = \text{Machine speed(rpm)} \]
\[ E_{\%} = \text{Efficiency in percentage} \]
\[ CPI = \text{Courses per inch} \]
\[ F_{\text{width(m)}} = \text{Finish width in meters} \]
\[ F_{\text{width(y)}} = \text{Finsh width in yards} \]
\[ F_{w(gsm)} = \text{Fabric weight in gram per square meter} \]
\[ F_{w(ozsm)} = \text{Fabric weight in ounces per square yards} \]

**Examples 9.6:**
Calculate the production in grams/hr if warp knitting machine running at 1800 rpm with 80% efficiency. The fabric produce has following parameters, width = 3 meters, fabric weight = 80 gsm, CPI= 36

**Solution:**

First we need to calculate the fabric production in running meter per hour.

We have.
\[ P_{rpmh} = \frac{M_s \times 60 \times E\%}{CPI \times 39.36} = \frac{1800 \times 60 \times 0.8}{36 \times 39.36} = 60.78 \]

To calculate the fabric in m²/hr, following relation can be used.

\[ P_{smph} = P_{rpmh} \times F_{width(m)} = 60.78 \times 3 = 182.34 \]

The fabric production in gram per hour is equal to

\[ P_{gph} = P_{smph} \times F_{w(gsm)} = 182.35 \times 80 = 14587.2 \frac{g}{hr} \]

So, the required production in gram/ hour is 14587.2 that is equal to 14.58 kg/hr.

9.9 Exercise

Problem 1: Calculate the yarn requirement in Kgs of 100% cotton and elastane yarn, if fabric is composed of 95% main and 5 % elastane yarn. The total required fabric is 1500 Kgs, keeping the wastage limit to 2% for each yarn.

Problem 2: Calculate the yarn requirement of each colour yarn of single jersey striper fabric with additional wastage of 3 percent. The repeat is given. The total required fabric is 5000kgs.

<table>
<thead>
<tr>
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<th>A= 40 Courses</th>
<th>B= 50 Courses</th>
<th>C= 20 Courses</th>
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Problem 3: A Calculate the production in pound per hour and yards per shift if the fabric is knitted on a single knit machine with following parameters, efficiency of the machine is 84% (Consider shift = 12h)

Number of Feeders = 20,

RPM = 25

S.L. = 0.38 cm

No of needle = 756
CPI= 24
Yarn Count=18/1

Problem 4: Calculate the Weight per linear meter of single jersey fabric made on a machine with following parameters. No of needle= 2040, CPI=28, Count =17s, S.L. = 80 Stitches per foot.

Problem 5: Calculate the production in pound /hr and meter/hr of 2 end terry fabric knitted with following parameters. Knit yarn Count +S.L. = 24/1 +0.38cm, loop yarn count +S.L. =16/1+0.13. Machine rpm= 16, Diameter/gauge= 30/18, total available feeder= 90.

Problem 6: Calculate the GSM of the 3 end terry fabric knitted with given parameters,
CPI= 35, WPI= 25, knit yarn +S.L. = 24/1 + 0.415cm, Tuck yarn +S.L. = 24/1 + 0.405cm, loop yarn + S.L.= 16/1+0.175cm

Problem 7: Calculate the Areal density of Swiss pique fabric knitted on Rib gated machine, the design consists of 4 courses (4 feeder), the S.L. of 1st and 3rd feeder is 0.28cm and 2nd and 4th feeder S.L. is 0.20cm, the yarn linear density is 30/1. The WPI and CPI of the fabric produce is 25 and 28.

Problem 8: Calculate the Areal density (g/m²) of 2 end terry fabric knitted with following parameters. CPI=30, WPI=22, knit yarn +S.L. = 30/1+0.42cm, loop yarn count + S.L.=12/1+ 0.17cm

Problem 9: Calculate the cams and needle required for cross miss design on single jersey machine. If designs are produce on machine with following parameters:
Diameter= 30, Gauge= 20, number of tracks available on machine= 2, total feeder = 90