The development of a novel high speed fabric manufacturing process

This item was submitted to Loughborough University's Institutional Repository by the/an author.

Additional Information:

- A Doctoral Thesis. Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University.

Metadata Record: [https://dspace.lboro.ac.uk/2134/10953](https://dspace.lboro.ac.uk/2134/10953)

Publisher: © Reinhards Vitos

Please cite the published version.
This item was submitted to Loughborough University as a PhD thesis by the author and is made available in the Institutional Repository (https://dspace.lboro.ac.uk/) under the following Creative Commons Licence conditions.

![Creative Commons License](https://creativecommons.org/licenses/by-nc-nd/2.5/)

**Attribution-NonCommercial-NoDerivs 2.5**

You are free:
- to copy, distribute, display, and perform the work

Under the following conditions:

**Attribution.** You must attribute the work in the manner specified by the author or licensor.

**Noncommercial.** You may not use this work for commercial purposes.

**No Derivative Works.** You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

Your fair use and other rights are in no way affected by the above.

This is a human-readable summary of the Legal Code (the full license).

For the full text of this licence, please go to:
http://creativecommons.org/licenses/by-nc-nd/2.5/
THE DEVELOPMENT OF A NOVEL
HIGH-SPEED FABRIC MANUFACTURING PROCESS

by


A Doctoral Thesis

Submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of the Loughborough University of Technology

April 1979

Department of Mechanical Engineering

ABSTRACT

The manufacture of conventional textiles usually involves either weaving or knitting. The author and his colleagues have devised a completely new technology for textile fabric construction involving the use of simple elements. These elements are basically similar in shape to sewing machine needles which interact with each other in such a way that yarns 'stitch-knit' themselves together to produce a fabric. As a result of this unique interaction the number of loops produced is doubled when compared to the time cycle of a conventional knitting action. Further enhancement of at least doubled fabric production rates should accrue from the dual effects of decreased yarn tensions and the lowered dynamic disturbing forces of the simplified knitting element manipulating system.

A survey has been made of the looped-type textile manufacturing processes and the most appropriate groups have been enumerated in order to form a basis of comparison for the novel process.

A basic study (including computer aided graphics) of probable textile structures, that could be produced by this technology, has revealed a substantial range of novel fabrics. These fabrics have been analysed and possible uses for them are suggested.

A powered research-rig has been designed and constructed on which the important yarn manipulation characteristics have been determined. This experimentation has facilitated a more positive yarn pick-up to be evolved. As a result of this, more practicable design tolerances may be given for the manufacture and setting-up
of the manipulative elements. Moreover, narrow-width novel fabric samples have been produced from spun-staple yarns at rates exceeding the current commercially available maximum, thereby substantiating the earlier predictions.

Finally, the new technology and its resulting products are appraised and design proposals for a prototype machine are made; it is hoped that this will be offered to industry in due course for further development and potential exploitation.
ACKNOWLEDGEMENTS

The author would like to express his indebtedness to the Science Research Council for sponsoring this work.

He would also like to express his appreciation to Professor G R Wray for supervision at the beginning of this research, for subsequent guidance and untiring encouragement and finally for skilfully editing the presentation of this thesis.

He also wishes to acknowledge the help afforded to him by many colleagues on the academic, technical, and secretarial staffs of the Department of Mechanical Engineering, but he would particularly like to mention the following individuals:

Dr J E Vine (now in industry) for his help in organising the manufacture of the research rig;

Mr S Walkinshaw for tolerance and observance of the basic principles at his starting on the current continuation of this development; and

Mr K W Topley, for taking the excellent photographs and the highly valued cine film.
**LIST OF ILLUSTRATIONS**

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Captions</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Plain weft-knitted structure</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Weft knitting cycle of operations when using latch needles</td>
<td>7</td>
</tr>
<tr>
<td>2.3</td>
<td>Weft knitting cycle of operations when using beaded needles</td>
<td>10</td>
</tr>
<tr>
<td>2.4</td>
<td>Plain or jersey weft-knitted structure</td>
<td>10</td>
</tr>
<tr>
<td>2.5</td>
<td>Rib-type weft-knitted structure</td>
<td>10</td>
</tr>
<tr>
<td>2.6</td>
<td>Single-bar warp-knitted structure</td>
<td>15</td>
</tr>
<tr>
<td>2.7</td>
<td>Four positions of warp knitting cycle of operations when using beaded needles</td>
<td>15</td>
</tr>
<tr>
<td>2.8</td>
<td>Raschel lace structures</td>
<td>24</td>
</tr>
<tr>
<td>2.9</td>
<td>Co-We-Nit knitting cycle - position (a)</td>
<td>28</td>
</tr>
<tr>
<td>2.10</td>
<td>&quot; &quot; &quot; &quot; (b)</td>
<td>28</td>
</tr>
<tr>
<td>2.11</td>
<td>&quot; &quot; &quot; &quot; (c)</td>
<td>28</td>
</tr>
<tr>
<td>2.12</td>
<td>Co-We-Nit structure (two seam interlacing)</td>
<td>30</td>
</tr>
<tr>
<td>2.13</td>
<td>Co-We-Nit structure (one seam interlacing)</td>
<td>30</td>
</tr>
<tr>
<td>2.14</td>
<td>Four positions of the 'Malimo' process</td>
<td>34</td>
</tr>
<tr>
<td>2.15</td>
<td>Three types of 'Malimo' structures</td>
<td>35</td>
</tr>
<tr>
<td>2.16</td>
<td>Five positions of half of 'Waltex' knitting cycle</td>
<td>38</td>
</tr>
<tr>
<td>2.17</td>
<td>'Waltex' knitted chains</td>
<td>39</td>
</tr>
<tr>
<td>2.18</td>
<td>'Waltex' knitted structure</td>
<td>39</td>
</tr>
<tr>
<td>3.1</td>
<td>Six positions of the 'Locstitch' cycle of operations</td>
<td>43</td>
</tr>
<tr>
<td>3.2</td>
<td>A seam of 'Locstitch' structure</td>
<td>46</td>
</tr>
<tr>
<td>3.3</td>
<td>A 'Locstitch' chain without the base fabric</td>
<td>46</td>
</tr>
<tr>
<td>Fig. No</td>
<td>Captions</td>
<td>Page No</td>
</tr>
<tr>
<td>--------</td>
<td>--------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>3.4</td>
<td>(a) Model seam</td>
<td>46</td>
</tr>
<tr>
<td></td>
<td>(b) 'Basic' Seam</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>Approximate needle tip orbits</td>
<td>49</td>
</tr>
<tr>
<td>3.6</td>
<td>Novel loop forming cycle of operations - position $(0^\circ)$</td>
<td>49</td>
</tr>
<tr>
<td>3.7</td>
<td>Novel loop forming cycle of operations - position $(60^\circ)$</td>
<td>50</td>
</tr>
<tr>
<td>3.8</td>
<td>Novel loop forming cycle of operations - position $(120^\circ)$</td>
<td>50</td>
</tr>
<tr>
<td>3.9</td>
<td>Novel loop forming cycle of operations - position $(180^\circ)$</td>
<td>51</td>
</tr>
<tr>
<td>3.10</td>
<td>Novel loop forming cycle of operations - position $(240^\circ)$</td>
<td>51</td>
</tr>
<tr>
<td>3.11</td>
<td>Novel loop forming cycle of operations - position $(300^\circ)$</td>
<td>52</td>
</tr>
<tr>
<td>3.12</td>
<td>Novel loop forming cycle of operations - position $(360^\circ)$</td>
<td>52</td>
</tr>
<tr>
<td>3.13</td>
<td>Pick-up triangle</td>
<td>54</td>
</tr>
<tr>
<td>3.14</td>
<td>Warp Knitting (a) Latch needle orbit (b) Yarn guide orbit (c) Graphs of displacements and accelerations</td>
<td>57</td>
</tr>
<tr>
<td>3.15</td>
<td>Novel process (a) R.H. needle orbit (b) L.H. needle orbit (c) Graphs of displacements and accelerations</td>
<td>57</td>
</tr>
<tr>
<td>4.1</td>
<td>Novel chain (a) 'Basic' seam (b) 'Basic' seam with one warp (c) 'Basic' seam with two warps</td>
<td>62</td>
</tr>
<tr>
<td>4.2</td>
<td>Novel chain (a) 'Alternative' seam (b) 'Alternative' seam with one warp (c) 'Alternative' seam with two warps</td>
<td>64</td>
</tr>
<tr>
<td>4.3</td>
<td>'Basic' pillar-seams connected by weft lays (a) edge view (b) face view</td>
<td>66</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Captions</td>
<td>Page No</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>4.4</td>
<td>'Basic' pillar-seams connected by weft lays and warp lays</td>
<td>66</td>
</tr>
<tr>
<td></td>
<td>(a) edge view</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(b) face view</td>
<td>66</td>
</tr>
<tr>
<td>4.5</td>
<td>'Alternative' pillar-seams connected by weft lays and warp lays</td>
<td>68</td>
</tr>
<tr>
<td>4.6</td>
<td>'Basic' pillar-seams connected by warp lays on one side only</td>
<td>68</td>
</tr>
<tr>
<td>4.7</td>
<td>'Basic' pillar-seams connected by warp lays on both sides</td>
<td>70</td>
</tr>
<tr>
<td>4.8</td>
<td>'Basic' pillar-seams connected by balanced warp lays on one side of fabric</td>
<td>70</td>
</tr>
<tr>
<td>4.9</td>
<td>'Basic' pillar-seams connected by balanced warp lays on both sides of fabric</td>
<td>71</td>
</tr>
<tr>
<td>4.10</td>
<td>'Basic' pillar-seams connected by two-seam lays</td>
<td>71</td>
</tr>
<tr>
<td>4.11</td>
<td>'Basic' pillar-seams connected by three-seam lays</td>
<td>72</td>
</tr>
<tr>
<td>4.12</td>
<td>'Basic' pillar-seams connected by selective-seam lays</td>
<td>73</td>
</tr>
<tr>
<td>4.13</td>
<td>'Alternative' pillar-seams connected by warp lays</td>
<td>75</td>
</tr>
<tr>
<td>4.14</td>
<td>'Alternative' pillar-seams connected by warp lays and wefts and warps</td>
<td>75</td>
</tr>
<tr>
<td>4.15</td>
<td>'Basic' seam interlaced structure</td>
<td>77</td>
</tr>
<tr>
<td>4.16</td>
<td>'Basic' two-seam interlaced structure</td>
<td>77</td>
</tr>
<tr>
<td>4.17</td>
<td>'Basic' selective-seam interlaced structure</td>
<td>79</td>
</tr>
<tr>
<td>4.18</td>
<td>'Alternative' seam interlaced structure</td>
<td>80</td>
</tr>
<tr>
<td>4.19</td>
<td>'Basic' seam interlaced structure and weft lays</td>
<td>80</td>
</tr>
<tr>
<td>4.20</td>
<td>'Alternative' seam interlaced structure and weft lays</td>
<td>82</td>
</tr>
<tr>
<td>4.21</td>
<td>'Alternative' seam interlaced structure and warp lays</td>
<td>82</td>
</tr>
<tr>
<td>Fig. No.</td>
<td>Captions</td>
<td>Page No</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>4.22</td>
<td>'Basic' seam interlaced structure and selective warp lays</td>
<td>84</td>
</tr>
<tr>
<td>4.23</td>
<td>'Basic' two-seam interlaced structure and weft and warp lays</td>
<td>84</td>
</tr>
<tr>
<td>5.1</td>
<td>'Basic' seam</td>
<td>87</td>
</tr>
<tr>
<td>5.2</td>
<td>'Basic' seam 1:2 scale</td>
<td>89</td>
</tr>
<tr>
<td>5.3</td>
<td>'Basic' seam 1:5 scale</td>
<td>89</td>
</tr>
<tr>
<td>5.4</td>
<td>'Basic' seam and warp lays</td>
<td>91</td>
</tr>
<tr>
<td>5.5</td>
<td>'Basic' seam and warp lays 1:2 scale</td>
<td>92</td>
</tr>
<tr>
<td>5.6</td>
<td>'Basic' seam and warp lays 1:5 scale</td>
<td>92</td>
</tr>
<tr>
<td>5.7</td>
<td>'Alternative' seam</td>
<td>94</td>
</tr>
<tr>
<td>5.8</td>
<td>'Alternative' seam 1:2 scale</td>
<td>95</td>
</tr>
<tr>
<td>5.9</td>
<td>'Alternative' seam 1:5 scale</td>
<td>95</td>
</tr>
<tr>
<td>5.10</td>
<td>'Alternative' seam and warp lays</td>
<td>97</td>
</tr>
<tr>
<td>5.11</td>
<td>'Basic' pillar seams connected by weft lays</td>
<td>99</td>
</tr>
<tr>
<td>5.12</td>
<td>'Basic' pillar seams connected by weft lays 1:2 scale</td>
<td>101</td>
</tr>
<tr>
<td>5.13</td>
<td>'Basic' pillar seams connected by weft lays 1:5 scale</td>
<td>101</td>
</tr>
<tr>
<td>5.14</td>
<td>'Alternative' pillar seams connected by weft lays</td>
<td>103</td>
</tr>
<tr>
<td>5.15</td>
<td>'Alternative' pillar seams connected by weft lays 1:2 scale</td>
<td>105</td>
</tr>
<tr>
<td>5.16</td>
<td>'Alternative' pillar seams connected by weft lays 1:5 scale</td>
<td>105</td>
</tr>
<tr>
<td>5.17</td>
<td>'Basic' pillar seams connected by warp lays</td>
<td>106</td>
</tr>
<tr>
<td>5.18</td>
<td>'Basic' pillar seams connected by warp lays 1:2 scale</td>
<td>108</td>
</tr>
<tr>
<td>5.19</td>
<td>'Basic' pillar seams connected by warp lays 1:5 scale</td>
<td>108</td>
</tr>
<tr>
<td>5.20</td>
<td>'Alternative' pillar seams connected by warp lays</td>
<td>110</td>
</tr>
<tr>
<td>Fig. No.</td>
<td>Captions</td>
<td>Page No</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>---------</td>
</tr>
<tr>
<td>5.21</td>
<td>'Alternative' pillar seams connected by warp lays 1:2 scale</td>
<td>112</td>
</tr>
<tr>
<td>5.22</td>
<td>'Alternative' pillar seams connected by warp lays 1:5 scale</td>
<td>112</td>
</tr>
<tr>
<td>5.23</td>
<td>'Basic' seam interlaced structure</td>
<td>114</td>
</tr>
<tr>
<td>5.24</td>
<td>'Basic' seam interlaced structure 1:2 scale</td>
<td>116</td>
</tr>
<tr>
<td>5.25</td>
<td>'Basic' seam interlaced structure 1:5 scale</td>
<td>116</td>
</tr>
<tr>
<td>5.26</td>
<td>'Alternative' seam interlaced structure</td>
<td>117</td>
</tr>
<tr>
<td>5.27</td>
<td>'Alternative' seam interlaced structure 1:2 scale</td>
<td>119</td>
</tr>
<tr>
<td>5.28</td>
<td>'Alternative' seam interlaced structure 1:5 scale</td>
<td>119</td>
</tr>
<tr>
<td>6.1</td>
<td>Apparatus for producing single seams</td>
<td>121</td>
</tr>
<tr>
<td>6.2</td>
<td>Model of 'Basic' seam</td>
<td>123</td>
</tr>
<tr>
<td>6.3</td>
<td>Model of 'Basic' seam and warp lays</td>
<td>123</td>
</tr>
<tr>
<td>6.4</td>
<td>Model of 'Basic' covered yarn</td>
<td>125</td>
</tr>
<tr>
<td>6.5</td>
<td>Model of 'Alternative' seam</td>
<td>126</td>
</tr>
<tr>
<td>6.6</td>
<td>Model of 'Alternative' seam and warp lays</td>
<td>126</td>
</tr>
<tr>
<td>6.7</td>
<td>Model of 'Alternative' covered yarn</td>
<td>128</td>
</tr>
<tr>
<td>6.8</td>
<td>Apparatus for producing multi-seam structures</td>
<td>129</td>
</tr>
<tr>
<td>6.9</td>
<td>Model of 'Basic' pillar seam structure (face and reverse views)</td>
<td>131</td>
</tr>
<tr>
<td>6.10</td>
<td>Model of distorted 'Basic' pillar seam structure</td>
<td>132</td>
</tr>
<tr>
<td>6.11</td>
<td>Model of 'Basic' pillar seam structure and warp lays</td>
<td>133</td>
</tr>
<tr>
<td>6.12</td>
<td>Model of 'Alternative' pillar seam structure and warp lays</td>
<td>135</td>
</tr>
<tr>
<td>6.13</td>
<td>Model of 'Basic' warp laced structure (face and reverse views)</td>
<td>137</td>
</tr>
<tr>
<td>6.14</td>
<td>Model of 'Basic' warp laced structure and warp lays</td>
<td>138</td>
</tr>
<tr>
<td>Fig. No.</td>
<td>Captions</td>
<td>Page No.</td>
</tr>
<tr>
<td>---------</td>
<td>---------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>6.15</td>
<td>Model of 'Alternative' warp laced structure and warp lays</td>
<td>138</td>
</tr>
<tr>
<td>6.16</td>
<td>Model of 'Basic' intermeshed structure (face and reverse views)</td>
<td>140</td>
</tr>
<tr>
<td>6.17</td>
<td>Model of 'Basic' two-seam intermeshed structure</td>
<td>141</td>
</tr>
<tr>
<td>6.18</td>
<td>Model of 'Alternative' intermeshed structure</td>
<td>143</td>
</tr>
<tr>
<td>6.19</td>
<td>Model of 'Alternative' two-seam intermeshed structure</td>
<td>143</td>
</tr>
<tr>
<td>7.1</td>
<td>Pictorial view of the rig</td>
<td>148</td>
</tr>
<tr>
<td>7.2</td>
<td>Subframe</td>
<td>150</td>
</tr>
<tr>
<td>7.3</td>
<td>Creel</td>
<td>152</td>
</tr>
<tr>
<td>7.4</td>
<td>Drives</td>
<td>153, 153a</td>
</tr>
<tr>
<td>7.5</td>
<td>Secondary drives</td>
<td>155</td>
</tr>
<tr>
<td>7.6</td>
<td>Needle drive mechanism</td>
<td>158</td>
</tr>
<tr>
<td>7.7</td>
<td>Needle primary motion</td>
<td>159</td>
</tr>
<tr>
<td>7.8</td>
<td>Needle secondary motion</td>
<td>159</td>
</tr>
<tr>
<td>7.9</td>
<td>Needle planar orbits</td>
<td>160</td>
</tr>
<tr>
<td>7.10</td>
<td>Needle incline</td>
<td>160</td>
</tr>
<tr>
<td>7.11</td>
<td>Needle pick-up shog</td>
<td>162</td>
</tr>
<tr>
<td>7.12</td>
<td>Fabric take-up</td>
<td>164</td>
</tr>
<tr>
<td>8.1</td>
<td>'Basic' seam</td>
<td>168</td>
</tr>
<tr>
<td>8.2</td>
<td>Knitting zone</td>
<td>169</td>
</tr>
<tr>
<td>8.3</td>
<td>Pick-up triangle</td>
<td>170</td>
</tr>
<tr>
<td>8.4</td>
<td>Needles with warp-wise eyes</td>
<td>173</td>
</tr>
<tr>
<td>8.5</td>
<td>Yarn distortions with warp-wise eyes</td>
<td>174</td>
</tr>
<tr>
<td>8.6</td>
<td>Yarn distortions with weft-wise eyes</td>
<td>174</td>
</tr>
<tr>
<td>8.7</td>
<td>'Basic' arrangement of needles</td>
<td>176</td>
</tr>
<tr>
<td>8.8</td>
<td>'Basic' pick-up shog</td>
<td>176</td>
</tr>
<tr>
<td>8.9</td>
<td>'Basic' one-seam intermeshing shog</td>
<td>176</td>
</tr>
<tr>
<td>Fig. No.</td>
<td>Captions</td>
<td>Page No</td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>8.10</td>
<td>'Alternative' arrangement of needles</td>
<td>177</td>
</tr>
<tr>
<td>8.11</td>
<td>'Alternative' pick-up shog</td>
<td>177</td>
</tr>
<tr>
<td>8.12</td>
<td>'Alternative' one-seam intermeshing shog</td>
<td>177</td>
</tr>
<tr>
<td>8.13</td>
<td>Knitting zone with presser bar</td>
<td>180</td>
</tr>
<tr>
<td>8.14</td>
<td>Grabber and needle arrangement</td>
<td>183</td>
</tr>
<tr>
<td>9.1</td>
<td>Plots of paths</td>
<td>185</td>
</tr>
<tr>
<td>9.2</td>
<td>Grabber primary displacement</td>
<td>187</td>
</tr>
<tr>
<td>9.3</td>
<td>Grabber secondary displacement</td>
<td>187</td>
</tr>
<tr>
<td>9.4</td>
<td>Grabber mechanism</td>
<td>188</td>
</tr>
<tr>
<td>9.5</td>
<td>Grabber 'z' displacement</td>
<td>189</td>
</tr>
<tr>
<td>9.6</td>
<td>Shogging module</td>
<td>191</td>
</tr>
<tr>
<td>9.7</td>
<td>'Alternative' weft-lay fabric</td>
<td>193</td>
</tr>
<tr>
<td>9.8</td>
<td>Needle shogging cams</td>
<td>195</td>
</tr>
<tr>
<td>9.9</td>
<td>Spring compensators</td>
<td>196</td>
</tr>
<tr>
<td>9.10</td>
<td>Yarn tension recording</td>
<td>196</td>
</tr>
<tr>
<td>9.11</td>
<td>Fabric sample</td>
<td>199</td>
</tr>
<tr>
<td>9.12</td>
<td>Twist-balancing of yarns</td>
<td>200</td>
</tr>
<tr>
<td>9.13</td>
<td>Dispersion of failures</td>
<td>202</td>
</tr>
<tr>
<td>9.14</td>
<td>Pick-up triangle (for pillar-seams)</td>
<td>205</td>
</tr>
<tr>
<td>9.15</td>
<td>Pick-up triangle (for left to right shog)</td>
<td>206</td>
</tr>
<tr>
<td>9.16</td>
<td>Pick-up triangle (for right to left shog)</td>
<td>208</td>
</tr>
<tr>
<td>9.17</td>
<td>Undercut grabber</td>
<td>210</td>
</tr>
<tr>
<td>10.1</td>
<td>Fabric samples</td>
<td>213 &amp; 214</td>
</tr>
<tr>
<td>10.2</td>
<td>'Alternative' fabric (face and reverse views)</td>
<td>216</td>
</tr>
<tr>
<td>10.3</td>
<td>The powered research rig</td>
<td>217</td>
</tr>
<tr>
<td>11.1</td>
<td>Proposed needle design</td>
<td>221</td>
</tr>
<tr>
<td>11.2</td>
<td>Proposed grabber displacement</td>
<td>221</td>
</tr>
</tbody>
</table>
LIST OF TABLES

TABLE 2.1  Classification of Warp Knitting Equipment  19
TABLE 2.2  The Range of Stitch-Bonding Processes and their Characteristics  32
TABLE 7.1  Table of Requirements  145
CONTENTS

ABSTRACT i

ACKNOWLEDGEMENTS iv

LIST OF ILLUSTRATIONS v

LIST OF TABLES xi

CONTENTS xii

CHAPTER 1: INTRODUCTION 1

1.1 Previous Investigations in High-Speed Textile Manufacturing Processes 1

1.2 Instigation of the Novel Process 3

1.3 Object of this Research 4

1.4 Terms of Reference 4

CHAPTER 2: SOME EXISTING KNITTING PROCESSES 5

2.1 Weft Knitting 6

2.1.1 Straight Bar Machines 11

2.1.2 Circular Machines 11

2.1.3 Flat Machines 12

2.2 Warp Knitting 13

2.2.1 Bearded Needle Machines 20

2.2.2 Latch Needle Machines 22

2.3 Co-We-Nit 26

2.4 Stitch Bonding 31

2.5 Waltex Machine 36

2.6 Process Productivity 37

CHAPTER 3: ORIGINATION OF THE NOVEL KNITTING SYSTEM 41

3.1 Principle of the Locstitch Process 41
3.2 The Intermeshing of Loops of Yarn to Form a 'Basic' Seam  44
3.3 The Intermeshing of Loops of Yarn to Form an 'Alternative' Seam  48
3.4 Accuracy of Needle Closure  53
3.5 Relative Dynamics of Loop-Forming  55
3.6 Potential Production Speeds  58

CHAPTER 4: LARGE-SCALE GRAPHICAL STUDY OF SOME POTENTIAL FABRIC STRUCTURES  60
4.1 The Single Seam as a Novelty Yarn Structure  60
4.2 Pillar-Seams Connected by Weft Lays  65
4.3 Pillar-Seams Connected by Warp Lays  67
4.4 Loops Intermeshed with Adjacent Wales  76
4.5 Loops Intermeshed with Adjacent Wales and Weft Lays  78
4.6 Loops Intermeshed with Adjacent Wales and Warp Lays  81
4.7 Loops Intermeshed with Adjacent Wales and Both Weft and Warp Lays  83
4.8 Summary  83

CHAPTER 5: THE USE OF COMPUTER-AIDED GRAPHICS IN THE INVESTIGATION OF FABRIC STRUCTURES  86
5.1 The Single Seam as a Novelty Yarn Structure  86
5.1.1 The 'Basic' Seam  86
5.1.2 The 'Alternative' Seam  90
5.2 Pillar-Seams Connected by Weft-Lays  96
5.2.1 The 'Basic' Type of Structure  96
5.2.2 The 'Alternative' Type of Structure  98
<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3</td>
<td>Pillar-Seams Connected by Warp-Lacing</td>
<td></td>
</tr>
<tr>
<td>5.3.1</td>
<td>The 'Basic-Type' Structure</td>
<td>102</td>
</tr>
<tr>
<td>5.3.2</td>
<td>The 'Alternative-Type' Structure</td>
<td>109</td>
</tr>
<tr>
<td>5.4</td>
<td>Loops Intermeshed with Adjacent Wales by Bridging Loops</td>
<td></td>
</tr>
<tr>
<td>5.4.1</td>
<td>The 'Basic-Type' Structure</td>
<td>109</td>
</tr>
<tr>
<td>5.4.2</td>
<td>The 'Alternative-Type' Structure</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td><strong>CHAPTER 6:</strong> LARGE-SCALE MODELS OF NOVEL STRUCTURES</td>
<td>120</td>
</tr>
<tr>
<td>6.1</td>
<td>The Single-Seam as a Novelty Yarn Structure</td>
<td></td>
</tr>
<tr>
<td>6.1.1</td>
<td>The 'Basic' Seam</td>
<td>120</td>
</tr>
<tr>
<td>6.1.2</td>
<td>The 'Alternative' Seam</td>
<td>122</td>
</tr>
<tr>
<td>6.2</td>
<td>Pillar Seams Connected by Weft-Lays</td>
<td></td>
</tr>
<tr>
<td>6.2.1</td>
<td>The 'Basic-Type' Structure</td>
<td>124</td>
</tr>
<tr>
<td>6.2.2</td>
<td>The 'Alternative-Type' Structure</td>
<td>130</td>
</tr>
<tr>
<td>6.3</td>
<td>Pillar-Seams Connected by Warp-Lacing</td>
<td></td>
</tr>
<tr>
<td>6.3.1</td>
<td>Model of a 'Basic-Type' Structure</td>
<td>134</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Model of an 'Alternative-Type' Structure</td>
<td>136</td>
</tr>
<tr>
<td>6.4</td>
<td>Loops Intermeshed with Adjacent Wales</td>
<td></td>
</tr>
<tr>
<td>6.4.1</td>
<td>Model of the 'Basic-Type' Structure</td>
<td>136</td>
</tr>
<tr>
<td>6.4.2</td>
<td>Model of an 'Alternative-Type' Structure</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td><strong>CHAPTER 7:</strong> DESIGN AND CONSTRUCTION OF THE POWERED RESEARCH RIG</td>
<td>144</td>
</tr>
<tr>
<td>7.1</td>
<td>Basic Concepts</td>
<td></td>
</tr>
<tr>
<td>7.1.1</td>
<td>Summary of the Needs</td>
<td>144</td>
</tr>
<tr>
<td>7.1.2</td>
<td>Conceptual Outline</td>
<td>146</td>
</tr>
<tr>
<td>Chapter</td>
<td>Title</td>
<td>Page No</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>7.2</td>
<td>General Structure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2.1 Stand</td>
<td>147</td>
</tr>
<tr>
<td></td>
<td>7.2.2 Subframe</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>7.2.3 Superstructure</td>
<td>149</td>
</tr>
<tr>
<td></td>
<td>7.2.4 Creel</td>
<td>151</td>
</tr>
<tr>
<td>7.3</td>
<td>Drives</td>
<td>151</td>
</tr>
<tr>
<td></td>
<td>7.3.1 Primary Drive</td>
<td>151</td>
</tr>
<tr>
<td></td>
<td>7.3.2 Secondary Drives</td>
<td>154</td>
</tr>
<tr>
<td>7.4</td>
<td>Needle Stations</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>7.4.1 Primary and Secondary Motion</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>7.4.2 Needle Shogging Motion</td>
<td>157</td>
</tr>
<tr>
<td>7.5</td>
<td>Yarn Feed</td>
<td>161</td>
</tr>
<tr>
<td>7.6</td>
<td>Fabric Take-up</td>
<td>163</td>
</tr>
<tr>
<td>8</td>
<td>INITIAl ACTUAL-SIZE EXPERIMENTATION VIA THE POWERED RESEARCH RIG</td>
<td></td>
</tr>
<tr>
<td>8.1</td>
<td>Looping by the 'Locstitch' Principle</td>
<td>166</td>
</tr>
<tr>
<td>8.2</td>
<td>Introduction of the 'Pick-up Shog'</td>
<td>167</td>
</tr>
<tr>
<td>8.3</td>
<td>Orientation of the Needle-Eye</td>
<td>171</td>
</tr>
<tr>
<td>8.4</td>
<td>The General Arrangement of the Elements</td>
<td>175</td>
</tr>
<tr>
<td>8.5</td>
<td>Addition of Presser-Bar</td>
<td>178</td>
</tr>
<tr>
<td>8.6</td>
<td>Basic Defect of the Process Reliability</td>
<td>179</td>
</tr>
<tr>
<td>8.7</td>
<td>Introduction of the 'Grabber'</td>
<td>181</td>
</tr>
<tr>
<td>9</td>
<td>DEVELOPMENT OF THE NOVEL PROCESS VIA THE POWERED RESEARCH RIG</td>
<td></td>
</tr>
<tr>
<td>9.1</td>
<td>Grabber Motion</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>9.1.1 Primary and Secondary Motion</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>9.1.2 Grabber Shogging Motion</td>
<td>186</td>
</tr>
</tbody>
</table>
9.2 Design of the Shogging Mechanisms
   9.2.1 Needle and Grabber Shogging Mechanisms
   9.2.2 Seam Interaction Shogging
9.3 Grabber Performance
9.4 Seam-Intermeshed 'Alternative' Fabric
   9.4.1 Seam Interaction
   9.4.2 Selvedges
9.5 Yarn Feed
9.6 Examination of Reliability Problem
   9.6.1 Yarns Used
   9.6.2 Dispersion of Failures
   9.6.3 Fluctuations in Yarn Tension
   9.6.4 Formation Consistency of Pick-up Triangle
   9.6.5 Position of the Pick-up Triangle
   9.6.6 Accuracy of Elements

CHAPTER 10: SUMMARY OF THE WORK TO DATE
10.1 Textile Aspects
10.2 Engineering Aspects

CHAPTER 11: PROPOSALS FOR FUTURE WORK
11.1 Textile Aspects
11.2 Engineering Aspects
   11.2.1 Needle Design
   11.2.2 Needle Primary Orbit
   11.2.3 Needle Shogging Motion
   11.2.4 Grabber Design
<table>
<thead>
<tr>
<th>Section</th>
<th>Page No</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.2.5 Grabber Motions</td>
<td>223</td>
</tr>
<tr>
<td>11.2.6 Prototype Machine</td>
<td>223</td>
</tr>
<tr>
<td>CHAPTER 12: CONCLUSIONS</td>
<td>226</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>227</td>
</tr>
<tr>
<td>APPENDIX I: Fortran Programme for Drawing the 'Basic' Seam</td>
<td>230</td>
</tr>
<tr>
<td>APPENDIX II: Fortran Programme for Drawing the 'Alternative' Seam</td>
<td>232</td>
</tr>
<tr>
<td>APPENDIX III: Specification of Major Bought/Out Transmission Equipment</td>
<td>235</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

By definition, the word "development" implies: gradual unfolding, fuller working out; stage of advancement; product; more elaborate form. If, as in this work, the word "DEVELOPMENT" refers to a textile manufacturing process, then a substantial gain in efficiency, or quality, or both should result.

The adjective "NCVEL" is defined as "of new kind or nature, (strange), hitherto unknown".

The hyphenated adjective "HIGH-SPEED" refers to the fabric manufacturing process and is used without a specified upper extent but is intended to indicate the opposite of "Low-speed".

In this work the words "FABRIC MANUFACTURING PROCESS" are specifically intended to describe a textile activity somewhat resembling "knitting", which is a means of converting textile yarns into some form of looped configuration, obtained by interlacing.

1.1 Previous Investigations in High-Speed Textile Manufacturing Processes

In 1967, Professor G R Wray and Mr G F Ward, members of the Department of Mechanical Engineering at Loughborough University of Technology, invented a sewing-knitting technique that aimed to produce a double-faced pile fabric. This technique proposed to use two yarns to form a type of stitch in which each pile loop was anchored or locked into a preconstructed base fabric.

Following on his extensive research and development activity on textile and manipulative machinery projects in industry, the
author's research at Loughborough on the production of unconventional pile-fabrics, which was presented as a thesis\(^1\) for the M.Tech. degree in 1970, described a high-speed method for stitch-knitting pile-loops into a preconstructed base fabric. The work was sponsored by the Science Research Council\(^2\), the basic stitch being produced on a small powered research rig, which was capable of stitching at very high speeds. Patents for the stitch and the apparatus\(^3\) were formulated and assigned to the National Research and Development Corporation (NRDC) in 1970, so that the invention could be commercially exploited. Edgar Pickering (Blackburn) Ltd., who entered into licensing agreements with NRDC in 1971, formed a subsidiary company, known as Pickering Locstitch Ltd., to produce commercial machines utilising the novel stitch. The new process was given the trade name of 'LOC-STITCH'. The prototype commercial Locstitch machine was designed within the Department of Mechanical Engineering at Loughborough University of Technology and was exhibited at the 6th International Exhibition of Textile Machinery, Paris 1971, with the author in charge of the practical setting-up and demonstrating the process. Substantial interest was aroused in the textile manufacturing industry and, since then, the Pickering Company has manufactured Locstitch machines, based largely on the University-designed prototype, principally for export sales.

The work was a classic example of University research and development, leading to commercial application, which should benefit both the textile industry and the consumer.
1.2 Instigation of the Novel Process

Spurred on by the high-speed potential of the 'Locstitch' stitch-knitting method, but fully appreciative of the severe economic limitations of the necessity to use a base fabric in the 'Locstitch' process, the author visualised the possibility to construct a sequence of connected loops into a looped-chain without the need for a preconstructed base fabric. The removal of the base fabric from a piece of Locstitch pile fabric resulted in a number of looped-chains. These looped-chains were distinctly different from the chains produced by other high-speed knitting or crocheting techniques. Such chains could be used as strings or speciality chainette effect yarns in other textile manufacturing processes.

High-speed covering of elastic yarns could also be considered, although a large commercial demand for such yarns may not exist and may be difficult to create. However, there is fierce competition for faster and more versatile textile fabric manufacturing processes and a major reason why this is likely to intensify is the vastness of the consumer market, the effect of which is accelerated by the growing labour costs.

It is well known that the fastest fabric manufacturing methods, such as warp and weft knitting as well as stitch-bonding and crocheting, use the intermeshing of loops to construct the resulting basic fabrics. By analogy, any attempts to elaborate the initial visualisation of the novel looped-chain into projected novel looped-fabrics, without losing the proven high-speed loop-forming potential, seemed to be justifiable objectives.
1.3 Object of this Research

In the previous section objective predictions of some novel yarn and fabric structures were made. Further comparison of the dynamic behaviour of the knitting elements on the Locstitch process with that of their equivalents on warp knitting machines suggested a minimum gain of doubling the number of loops produced per unit time. It is well known that many potentially useful inventions have failed, or have been lost to foreign competition, due to insufficient basic research and/or lack of pre-prototype development work being undertaken. It was the considered intention of this activity thoroughly to investigate the nature of the special yarn and fabric structures that could result from the novel loop formation principle, together with practical experimentation at all stages, so as to permit a clear assessment of the novel process.

Design proposals were to be made, for a prototype machine, based on this experimentation and on the objective assessment of the produced chainette yarns and fabric samples.

1.4 Terms of Reference

Subject to the objectives described in the above section, an SRC sponsored research grant was granted in 1974 for a duration of three years. Substantial progress was made, although clear proposals could not be passed on to industry; hence further financial support from SRC was sought and obtained as a three years extension to the earlier grant.
CHAPTER 2

SOME EXISTING KNITTING PROCESSES

Knitting is a process in which rows, or courses, of looped stitches are formed into certain types of fabric structure such that each knitted course is looped in with adjacent courses. The knitted structure may be formed either by weft knitting, in which one or more individual weft supply yarns are laid across beds of needles so that loops of yarn are drawn through previously made loops, or by warp knitting, in which case the fabric is formed by looping together parallel warp threads as they are fed collectively from a warp beam.

Knitting is becoming an increasingly strong competitor for many of the fields traditionally associated with woven fabrics, e.g. shirtings, suitings, dress fabrics, furnishing fabrics, and sheetings, as well as retaining its conventional uses in hosiery, underwear, and knitted outerwear. Knitted fabrics are often used where porosity and extensibility are desirable qualities, since the knitted loop gives a relatively open structure compared with weaving, and this can be further enhanced if the stretch types of textured yarn are used. It is also possible to make bulky fabrics without their being unduly heavy.

The basic knitting processes are well-known and their products are used extensively; however, the same is not true with some more recently introduced developments, e.g. stitch-bonding techniques and the Waltex process. 18 It is acknowledged that, in the free economies, the criteria for acceptance and progress of new technologies and their products are very complex, and yet the optimum economy of unit cost is
an important factor of the whole. Hence, in order to facilitate the establishment of the relative potentiality of the novel knitting process, that is the basis of this current investigation, the basic loop generating mechanics of some of these existing processes are briefly summarised in the following sections.

2.1 Weft Knitting

The diagrams and some of the text used in Sections 2.1 and 2.2 are by kind permission of Professor G R Wray.33

Figure 2.1 shows the simplest type of weft-knitted structure, namely, plain (or Jersey) knitting. Horizontal rows of loops are called courses, and the rows of loops down the fabric are known as wales. Thus, if a circular weft knitting machine is producing this type of fabric, the number of wales will be the same as the number of needles in the cylinder of the machine, the number of courses per inch depending on the size of stitch being produced, i.e. on the stitch length.

Figure 2.2 illustrates how this basic type of knitted stitch is produced by a simple vertical reciprocating movement using a latch needle. It should be noted, however, that this is an end view of one typical needle only, and that identical needles will be operating in just the same manner immediately before and behind it so that a continuous knitted fabric is produced rather than the simple "one-wale" row of stitches shown. At position (a) the needle is rising, the previously formed loop serving to hold the latch open. When the needle has risen to its top-most position (b), the previously formed loop has been cleared below the latch, and new yarn is fed into the
FIGURE 2.1

C = ONE COURSE
W = ONE WALE

FIGURE 2.2
needle hook. The needle then descends to its lowest position (c) so that the newly fed loop of yarn is drawn through its immediate predecessor, which is now cast off to form part of the knitted fabric body. In being cast off, however, it also performs a useful function in closing the latch to retain the new loop. Then the cycle of operations restarts as the needle rises through position (a) again.

The first knitting machine, the stocking frame, was invented by the Rev. William Lee in 1589, and his ingenious invention incorporated the bearded needle in its mechanism. Bearded needles are still used in some of the most modern machinery, and Figure 2.3 shows how simple plain knitting is achieved using such needles. When the needle has risen to its top position (a), yarn is fed on the needle stem to form a loop below the beard of the needle. The needle then moves downward to position (b), where the newly formed loop is trapped under the beard, which is then closed by an externally applied presser by forcing the tip of the beard into a groove in the stem. As the needle continues downward, the previously formed loop slips over the closed beard, whereupon the pressure on the beard can be released. The stitch is completed at position (c) when the needle has reached its lowest position and the new loop has been drawn through the previous loop as the latter has been cast off to form part of the knitted fabric body. The new loop is then positioned in the crook of the needle, but it is moved down the stem of the needle as the needle rises again to position (a) to complete the cycle.

In most circular weft knitting machines the vertical movement is imparted to the needle butts as the needles in their revolving cylinder pass over stationary cam tracks mounted on the machine frame.
around the cylinder. Hence, if the positions of the tracks are suitably adjusted, or if different types of cams are substituted, more complicated variations of this basic stitch may be produced to give variety to the knitted structure. For instance, particular needles need not knit at one or more particular yarn feeder stations; tuck stitches may be formed by using cams which cause the needles at one particular feeder to rise only to the tuck position, Figure 2.3a where the needle is able to receive the new loop without having cleared the old loop below the latch.

Even more variety can be obtained by introducing a second set of needles in a dial which has its needles positioned radially so as to be at right angles to the cylinder needles. Then the yarn feeders can incorporate a yarn-changing mechanism, so that extra yarns may be introduced when required by the particular knitted pattern or design, or alternative colours or yarn types may be substituted during the process. Also, if jacquard selection mechanisms are incorporated, complex patterns can be produced for effect purposes. As is the case in jacquard weaving, the pattern has first to be transferred from design paper in codified form to cards or tapes, usually as a series of punched holes, before it is suitable for actuating the appropriate knitting elements. However, in relation to loop appearance, machines equipped with one set of needles produce a distinctive type of loop structure known as "plain" or "jersey" (see Figure 2.4). Knitting machines with two sets of angularly opposed needles produce a loop structure known as "rib" (see Figure 2.5). Another feature of some machines is the provision for fashioning (i.e. shaping) of garments, which is accomplished by devices that automatically increase or decrease the number of stitches in successive courses.
FIGURE 2.3

FIGURE 2.4

FIGURE 2.5
From the foregoing, it will be appreciated that knitting machinery is often very complex and defies detailed treatment in this thesis. However, an introduction to the various types of weft knitting machinery may be attempted by a subdivision into the three main generic classes discussed below.

2.1.1 Straight Bar Machines

These are direct descendants of the 1589 stocking frame invented by William Lee. However, the main improvement for power operation and the automatic widening or narrowing of the fabric to make fashioning possible on a continuous basis was invented by William Cotton in 1864, and machines of this type are often called "Cotton's Patent" machines. The straight bar frame fashions flat pieces of fabric by knitting them to the required shape using bearded needles in conjunction with loop-forming elements known as sinkers; in this machine the cam is not stationary, the needle bars being actuated in a complex pattern by a radial camming system, and the sinkers by the traversing of a plough-type cam known as a slurcock. Because each garment section is knitted to shape, fashioned knitted goods usually have a better appearance than cut-and-sew knitted garments. Although a saving results from the absence of cutting waste, the production of fashioned garments is inherently slower and it is therefore used mainly for high-quality knitted underwear and outerwear.

2.1.2 Circular Machines

Circular machines may use either latch needles or, less commonly, bearded needles. Depending upon the type of product, the cylinder
diameters used vary from about 2 in. (for children's socks) up to 36 in. or more (for piece goods and jersey fabric). At the smaller end of the scale there are the various types of footwear machines which can make welts, heels, and toes, as well as provide for fancy stitches and complex patterning when required. Circular-knitted ladies' stockings have become very popular because the use of nylon yarns has made shaping by heat-setting practicable, and the demand for such seamless hose has provided the impetus for developments leading towards automation of the process; the vogue for tights, however, can also be met by circular hosiery machines for the leg sections; the gussets can be produced separately on either flat or straight-bar machines. Larger circular machines are used for fabric intended for cut-and-sew underwear or outerwear garments, or for dress fabrics and similar piece goods. Such machines incorporate many varied mechanisms for pattern selection (jacquard principle) and for the provision of various types of knitted fabric structures, e.g. interlock, double jersey, rib structures, eyelet fabric, etc. From this very brief survey, it will be gathered that circular weft knitting is highly specialised, and that a far more detailed treatment would be necessary to do justice to its commercial importance as a fabric production technique.

2.1.3 Flat Machines

In certain respects, flat machines can be considered as opened-out versions of circular weft knitting machines, although this is a gross over-simplification. The needles are arranged in flat beds, and these are actuated by a traversing cam carriage. Most hand-operated home-knitting machines are simplified versions of flat
machines; some of the commercial machines are also hand operated to allow for mechanical complexity, and a great deal of operator skill is involved in producing intricate patterns and surface designs in bulky knitted sweaters and similar garments. The "V"-type rib machine is often power-driven and largely automatic in operation, and insofar as loop formation is concerned, has similar characteristics to the cylinder and dial types of circular knitting machine. Comparatively speaking, however, there is greater scope for patterning on the flat machines, but the process is slower and therefore less productive. Cable stitches and similarly complex knitted structures are ideally produced on the flat machine, and colour changing and striping are more easily performed than on circular types. There is also a growing tendency for fashioning facilities to be incorporated on modern flat machines.

2.2 Warp Knitting

In warp knitting, each needle can be supplied with either a separate yarn or with several yarns. The simplest type of single-bar fabric is shown in Figure 2.6 where it can be seen that each warp yarn is caused to zigzag along the length of the fabric; this forms a loop at every change of direction as individual yarns are intermeshed with adjacent yarns which have similarly contorted paths. As with weft knitting, each row of loops running along the fabric is known as a wale, and each row of loops running across the fabric is a course, but in warp knitting the loops in one course are produced simultaneously. This, coupled with the fact that each yarn usually traverses a horizontal distance of only one or two needle spaces during the formation of a knitted course, makes warp knitting
highly productive when compared with weaving.

The simple fabric shown in Figure 2.6 serves to illustrate the principle, but would be too unstable for practical use. In order to make more stable fabrics, two or more sets of warp yarns are used, resulting in a straight wale structure if at least two yarns forming each loop are wrapped around the needle under suitable tensioning conditions. The warp yarns are supplied on beams, there being usually one beam per guide-bar assembly; tension devices must be provided to absorb the excess lengths of yarn which may occur at certain stages of the knitting cycle, as well as to provide the tension necessary for the formation of stable loops. As with weaving, the let-off of warp threads may be based on negative methods, in which case the yarns themselves pull the beams around, or alternatively a servo-controlled positive drive to the beams may be used to feed the yarns at the correct speed for knitting.

The needles used in warp knitting may be either of the bearded or latch types, but a compound tubular type of needle has also been employed in some machines. Bearded needle warp knitting, in its simplest form, is illustrated in Figure 2.7. In position (a) the guide bars, G, are moving away from the front of the machine to pass the warp threads through the spaces between needles. Each needle, N, is still rising, having just knocked over the previous stitch and having left it held by the throat of the sinker, S. An overlap has been formed over the needle beard when position (b) is reached, as the guide bars have been shogged slightly sideways before moving forward; the needle has risen to slip this lap on to the needle stem.
The needle descends to position (c), the presser, P, having closed the beard to trap the newly lapped thread. The sinker retracts to allow the fabric to be lifted from its throat so that the previously made stitch is landed on the outside of the needle beard. The cycle is completed at position (d) when the needle has descended to its lowest position, having caused the previously formed fabric loop to be knocked over the needle heads as the fabric is again brought into the sinker throat, which has moved forward appropriately. The guides then take up a new lateral position ready to perform a similar operation on another needle.

Thus one can see that, although the needles remain in the same vertical plane, the guide bars are able to be shogged sideways by one or more needle pitches. When the shogging motion occurs on the beard side of the needle, as between positions (a) and (b), it makes an overlap; when it occurs in front of the needles, as between positions (d) and (a) an underlap is formed. The provision of up to 48 different guide bars, each capable of independent lateral shogging motions, together with an additional needle bar in some cases, enables very intricate patterns to be knitted. In such cases a visual representation of the required fabric design has to be translated onto either pattern chains or pattern wheels to actuate the guide bars. The scope for variation in fabric design is wide indeed, but is limited by the physical problem of fitting so many mechanical parts into the knitting region.

The reader will appreciate that the simple cycle of operations shown for producing the basic stitch using a bearded needle could just as easily have been represented using either a latch needle or a compound needle, as the principle remains unchanged. The only points of detail are that, instead of a presser being used to close
the beard, the latch is closed by the action of taking the previously formed loop over it, similar to the action shown for weft knitting (Figure 2.2): in the case of the compound needle, a mechanically operated tongue, positioned inside the hollow needle stem, bridges the gap between the needle stem and the hook, thus obviating the need for a negatively closed latch, but introducing an extra positively driven element in the same way that the presser is an extra positively driven element when it closes the latch needle.

End-uses of warp-knitted fabrics include sheetings, shirtings, fancy lace, nets, curtains, thermal cloths, packaging bags, upholstery and other loop-raised fabrics, simulated suede, as well as many types of lingerie and dress fabrics. Hence warp knitting is not only a competitor in many fields traditionally associated with lace making and weft knitting, but it also rivals weaving in some of its outlets, principally because of its very high rates of production which can be in excess of 1000 courses per minute. Machines suitable for many fabric types are often 168 in. wide, and widths can be as great as 240 in. on some curtain net machines; such machine widths also increase their competitiveness on the basis of output per machine.

One disadvantage of warp knitting is that it is mainly suitable for filament yarns rather than for spun staples. The fabric structures produced by warp knitting, although at first glance often similar to woven fabrics in certain constructions, e.g. filament nylon shirtings, cannot as yet simulate woven fabrics entirely. No weft is used and, therefore, the high stability of a closely interwoven fabric is hardly realised; moreover, the varied weft effects which are cleverly exploited in many types of weaving are not possible by
the very nature of the process. However, it is interesting to note that warp knitting machines have emerged in recent years that incorporate the laying in of weft threads during the process; there is no doubt that such developments will continue to increase the versatility of the knitting process.

A range of commercially available warp knitting equipment in generic groups is shown in Table 2.1. The first division of machines of both types of needles relate to the number of needle bars used. The double needle bar tricot is called Simplex. There is no special name for double needle bar Raschels. Double needle bar equipment normally produces two-faced fabrics with the exception of carpeting or other pile constructions.

The division according to needle bar number is similar to one existing in weft knitting (see Section 2.1) which divides the equipment into plain (one set of needles) and rib (two sets of needles). The number of machine variants is too large to be detailed here; however, it might be beneficial to outline at least some of the machines and the fabrics they produce.

Several experts have recognised the immense importance of the warp-knitted fabrics on the modern world economy and subsequently have produced detailed explanatory surveys of this branch of knitting technology. For this study the author has drawn references from two significant publications: "Warp Knit Engineering" by A Reisfeld and "Warp Knitting Technology" by D F Paling.
TABLE 2.1
Classification of Warp Knitting Equipment

Latch Needle
- Single Needle Bar
  - Raschel
  - General Purpose
    - Tubular
      - Crochet
      - General Purpose
        - Carpet
        - Tulle

Bearded Needle
- Single Needle Bar
  - Raschel
- Double Needle Bar
  - Flat Milanese
  - Circular Milanese

Tricot
- Two Bar
  - Speciality
    - Jacquard
      - Split Needle Bar
      - Solid Needle Bar
- Multi-Bar
  - Cut Press
    - Chain Loom
    - Stocking

Guide Selection
- Needle Selection
2.2.1 Bearded Needle Machines

The single needle bar machines are divided into two main groups called Milanese and tricot.

There are several types of Milanese machines but for convenience these may be further grouped into (i) Flat Milanese and (ii) Circular Milanese.

(i) The Flat Milanese machine is invariably a bearded needle machine similar in construction to tricot but different in its mode of loop-forming action. The pattern scope is very restricted because of constructional features of the machine which permit the manufacture of only a few basic fabrics. Milanese merchandise, because of its excellent qualities, for a long time enjoyed the highest reputation. Nevertheless, the low output, mechanical complexity and lack of pattern potentialities of the flat Milanese process brought about its rapid decline in post-war years.

An attempt has been made to revive the Milanese trade in East Germany where a new high speed unit has been evolved. It has a flat needle bar and is capable of running at 400 courses per minute. However, patterning and other limitations have not been removed and hence there is little possibility of it succeeding.

(ii) Circular Milanese machines utilise either bearded or latch needles. Modern machines are capable of reasonably high speed, i.e. 450 to 600 courses per minute. They are built in gauges of 14 to 30 needles per inch and are up to 28 inches in diameter. Fabrics made in coarse gauge machines were in good demand in the European outerwear trade, but the circular Milanese process is now rapidly losing ground, mainly, due to its inferior prod-
uction economics as compared to tricot and to its very limited patterning scope. In fact, there is little the Milanese machine can do that cannot be done on a tricot machine at a lower cost.

iii) The largest group of single bearded needle bar machines is the tricot machine family. From this, the two guide bar tricot is the 'workhorse' of the jersey industry. The machines are usually 84 in. wide in Europe and 168 in. in the U.S.A.

The three-bar tricot machine is used for more advanced pattern work. These machines are either 84 or 168 in. wide and almost invariably in 28 gauge.

Cut presser machines are used for knitting fabrics featuring surface and raised effects created through loop accumulation. They usually consist of three guide bars, a plain presser and a cut presser bar. The most used gauges are 28 and 14, and the widths vary from 84 to 168 in.

The most versatile of the bearded needle group is the Jacquard tricot. This equipment provides almost unlimited scope in the area of openwork patterns by the application of a Jacquard attachment which selects and actuates individual guides. A selected guide is displaced laterally to coalesce with the adjacent one and swing through its pair of needles. In this way, the needle normally lapped with the yarn of a selected guide will miss it and so create an openwork effect.
2.2.2 Latch Needle Machines

The Raschel industry is much more diversified than tricot and consequently its equipment comprises a greater range of machine types. From the classification (Table 2.1) it may be observed that the general division again occurs between single and double needle bar equipment with the exception of the crochet machines and the general purpose Raschel. The machine variants are extensive, for the speciality Raschels, in particular, but the following are enumerated below: (i) General purpose Raschel; (ii) Lace machines; (iii) Net machines; (iv) Carpet machines; (v) Jacquard machines; (vi) Speciality Raschel machines.

i) The general purpose Raschel was the main producer in the industry until the beginning of the post-war era. Most of them were 80-90 in. long and in 18-30 gauge. They invariably carried six guide bars and there was always a provision for a second needle bar. Many machines were equipped with the following attachments: fall plate, stitch comb, crepe attachments, chain automat, fringing device, plain and cut plush points, weft inlay mechanism. Many hundreds of these machines are still used by the industry both in Europe and elsewhere. However, due to the machine's complexity, as the experienced mechanic technicians retire from their employment, these machines often fall into disuse. The new generation of mechanics having been trained in narrow, specialised fields find it difficult to cope with the general purpose equipment and consequently it faces a gradual but inevitable decline. With the exception of multi-bar lace, the general purpose machine can produce almost anything that a specialised machine does, but it is greatly inferior production-
wise. Many of the modern specialised Raschels have three to four times the output of the general purpose machine. As new Raschel products are being developed and knitted in large volumes, one can anticipate the introduction of more specialised equipment designed for fast and economical manufacture of such products.

ii) Raschel lace machines form the largest and most important group in the industry. The low bar models comprising 6 to 14 bars are giving way to new high-speed multi-bar machines of 18, 24 and 30 bars. Usually, three to four knitting bars are utilised for knitting the ground structure on which the inlay pattern is developed with the aid of nested pattern bars. These multi-bar machines, being designed for optimum performance on lace articles only, would not be sufficiently efficient and competitive if used in fields unrelated to lace. They carry no provision for mounting of the second needle bar nor for any of the attachments available with the general purpose machine. The lace machines are built in 50-124 in. widths and 18-42 gauges. A typical Raschel lace structure is shown in Figure 2.8.

iii) The Raschel net machines are specially designed for knitting all types of net, mesh and tulle constructions. However, in the search for ever higher manufacturing efficiency, three distinct types of units have been evolved: (a) Power net machines, (b) Tulle machines, (c) Fishing net machines.

(a) The Power net machines produce openwork elastic cloth for foundation garments. Plain units carry four guide
bars but, for patterned nets, 8-12 bar units are used.
The equipment is available in 65-172 in. widths and
30-64 gauges.

(c) *Tulle machines* are employed for the production of tulles,
   nets and meshes, either plain or patterned. They usually
carry four guide bars and have widths up to 240 in. and
gauges up to 48.

(c) *Raschel fishing net machines* are made in medium and coarse
gauges for the purpose of knitting various kinds of fishing
nets which have been found more economical and mechanically
superior to regular knotted nets.
Other net products may also be made on these units for
such end uses as play pens, laundry and dye bags, swimming
pool covers, storage racks, sporting nets, ornamental and
protective packaging, industrial nets and many other types
of network structures.

iv) *Raschel carpet machines* made their progress in the industry
during the time that the tufted carpet became a volume product
in many world markets. Special equipment was developed invol­
v­ing the use of a two-needle bar system with one proper needle
bar and one point bar around which the pile loops are drawn.
Carpet Raschels are massively built to withstand the knitting of
fabrics weighing several pounds per square yard. The machines
are 100-200 in. in width and 14-30 gauge.

v) *Jacquard Raschel machines* are designed primarily for the manu­
facture of openwork structures like curtains, lace, furnishing,
etc. Basically, the machine knits a three bar marquisette on
which inlaid gimp patterns are created. The jacquards select guides to operative or idle positions. The guides selected to operative position receive a motion which causes their threads to appear on the marquisette ground as a pattern inlay. The jacquard machines are available in widths of 125 in. and gauges of 9-18 needles per inch.

vi) Speciality Raschel machines are built in large variety for a narrow range of products such as tubing, strapping, rib borders, speaker grillcloth, packaging materials etc. The productivity of each particular unit is very high but it is more difficult to adapt it for the manufacture of a different product.

2.3 Co-We-Nit

The Combined-Weaving-Knitting machine, now known as the Co-we-nit machine\textsuperscript{27,28} was introduced to the industry at the Basle Textile Exhibition\textsuperscript{26} in 1967. The unique fabric is made on a Raschel machine of novel design incorporating a special knitting motion and a fall-plate mechanism.

The following text and illustrations (Figures 2.9 to 2.13) of the knitting cycle (trade brochure 29) are by kind permission of Karl Mayer Textilmaschinenfabrik GmbH, 6053 Obertshausen, Germany.

The knitting construction consists of a pillar stitch on bar 1 with a weft laying under several needles on bar 2. On bars 3 and 4, filler threads are employed to obtain greater density and stability in the fabric. It is important to note that the weft is not laid in one underlap movement but in two stages, an overlap and an underlap.
Depending upon the pattern required, the filler threads are displaced so as to avoid the weft and thus lie on the face of the fabric. Without any, or with an insufficient amount of displacement, the warp ends lie on the back of the fabric.

The knitting cycle is as follows:

i) The needles are at their lowest point. Bar 2 (L2) makes an underlap one needle to the left. Bar 3 (L3) makes an underlap one needle to the left as the first stage of the displacement.

ii) The latch needles rise. The guide bars swing through. Bar 2 (L2) makes an overlap one needle to the right (see Figure 2.9).

iii) The needles remain in their highest position. The guide bars swing to the front. The fall-plate pushes the laid threads of bar 2 (L2) below the latch (Figure 2.10).

iv) The needles remain in the highest position. Bar 3 (L3) makes one needle underlap to the right. This is the second stage of the displacement.

v) The needles remain in their highest position. The fall-plate rises and the guide bars swing backwards.

vi) The needles remain in their highest position. Bar 1 (L1) makes one needle overlap to the right (Figure 2.11).

vii) The needles remain in their highest position. The guide bars swing to the front.

viii) The needles move down to the lowest position and thus form loops from the ends on bar 1 (L1).

The advantages of this structure are as follows:
The pillar stitch combined with a lay-in is, in itself, stable. An extension of the weft gives an even greater stability in the fabric width and additional filler ends result in further stability in the length as well as resistance to tearing. The percentage of fine ends is very low as only one guide bar forms loops (the pillar stitch on bar I). Only one bar with weft threads is needed to hold one or more filler threads between two pillars.

As the filler threads can be arranged as required in front of or behind the weft, different pattern constructions can be produced and since the stable combination of pillar stitch and lay-in threads lies in between, it is not affected even by high abrasion.

Figures 2.12 and 2.13 show two further fabric structures which could be compared to dobby patterning in weaving.

It can be clearly seen from Figure 2.12 that two filler ends from each of the two back guide bars lie alternately above and below the surface; thus there are a total of four filler threads between two pillars. The two back guide bars are therefore twice as fine in gauge as the needle bar itself. During the loop forming process of bar I (Li), the filler threads in bars 3 and 4 are in a position determined by a number 4 height chain link. In the case of a lateral displacement over two chain link heights, the two filler threads lie in front of the weft. In the case of a sideways displacement by only one chain link height only one of the threads from a guide bar can be displaced and come to lie in the front of the weft wales, the other remaining behind the weft.

The gauge of Co-we-nit machines depends on the number of guides in a 2 in. section of the rear guide bars in combination with the number of needles in 2 in. working width, e.g. 48/24 gauge.
FIGURE 2.12

FIGURE 2.13
Two types of Co-we-nit machines are available:

i) High-speed Raschel machine with 4 guide bars and a fall-plate.

- **Working widths:** 75, 90, 105 and 124 inches.
- **Gauges:** 24/12 gauge (i.e. bar 1, bar 2 and needle bar in 12 gauge, bar 3 and bar 4 in 24 gauge).
- **28/14, 32/16, 36/18 and 48/24 gauge.**
- **Speed:** 350 rpm (2 laying motions per course).

ii) Raschel machine of RM basic construction with 4 guide bars and fall-plate.

- **Working width:** 65, 75, 90, 100 and 124 inches.
- **Gauges, convertible:** 24/12, 28/14, 32/16, 36/18 and 48/24 gauge.
- **Speed:** 250 rpm (2 laying motions per course).

Co-we-nit fabrics are used for ladies' and mens' outerwear, upholstery, furnishing fabrics, drapery, household linen and industrial cloths.

### 2.4 Stitch Bonding

Some twenty years ago, the Czechoslovakian Knitting Industries Research Institute first commercially exploited a sewing-knitting technique for producing Arachne stitch-bonded fabrics. Since then a substantial range of stitch-bonding processes have evolved and a survey made in 1977 (Table 2.2) shows at least nine different types of commercially available machines. In general, stitch-bonding
TABLE 2.2
The Range of Stitch-Bonding Processes and their Characteristics

<table>
<thead>
<tr>
<th>ARABEVA</th>
<th>MALIVLIES</th>
<th>Loose staple-fibre web only</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARACHNE</td>
<td>MALIWATT</td>
<td>Loose staple-fibre with stitching warp or warps</td>
</tr>
<tr>
<td>ARAKNITT</td>
<td></td>
<td>Stitching warps only</td>
</tr>
<tr>
<td>ARUTEX</td>
<td>MALIMO</td>
<td>Stitching warps binding weft way yarns with extra pile warp</td>
</tr>
<tr>
<td></td>
<td>SCHUSSOPOOL</td>
<td>Stitching warps binding weft way yarns with extra pile warp</td>
</tr>
<tr>
<td>ARALOOP</td>
<td>MALIPOL</td>
<td>Stitching warp as pile stitching into a base cloth or web</td>
</tr>
<tr>
<td></td>
<td>VOLTEX</td>
<td>Loose staple-fibre web as pile stitched into a base cloth</td>
</tr>
<tr>
<td>BICOLOUR ARALOOP</td>
<td></td>
<td>Stitching warps knitted into both sides of a base cloth on a double needle bed</td>
</tr>
<tr>
<td>LIROPOL</td>
<td></td>
<td>Triple warp machine forming double-sided pile</td>
</tr>
<tr>
<td>KRAFTAMATIC</td>
<td></td>
<td>Stitching warp as pile stitching into a base cloth</td>
</tr>
</tbody>
</table>
processes use pointed compound needles as stitching needles to pierce the prepared weft layers, base fabrics or fleeces. Guide needles lay the sewing threads into the hooks of the stitching needles. In order to form the stitches, the hooks are covered temporarily by closing wires. A typical cycle of operation is shown in Figure 2.14 at four positions of the Malimo (East Germany) process:

Position (a) - stitching needles are just piercing the weft layers whilst carrying the old loops in the hooks.

Position (b) - the needles are through the weft sheet, the old loops (7) have been pushed on to the shank of the needles. The guides have laid yarns (8) in the open hooks.

Position (c) - the needles are retracting, carrying the new loops in their hooks which are covered by the closing wires (2).

Position (d) - needles are fully retracted, new stitches (10) are held in hooks, the structure is progressing one course downwards.

Figure 2.15 illustrates, diagrammatically, three types of Malimo structures:

Type (a) - Tricot stitch with three thread systems;

Type (b) - Tricot stitch with two thread systems; and

Type (c) - Closed chain stitch.
1 stitching needles  
2 closing wires  
3 sewing-thread guide needles  
4 knocking-over sinkers  
5 retaining pins

6 supporting rail  
7 stitches of the previous course  
8 newly laid sewing threads  
9 weft threads  
10 new stitches

FIGURE 2.14
(a)

(b)

(c)

\(a=\text{sewing thread}\)
\(b=\text{weft thread}\)
\(c=\text{warp thread}\)

**FIGURE 2.15**
2.5 Waltex Machine

In 1961 a unique knitting machine named the Waltex TWF/180 was introduced to the industry. Conventional needles and sinkers are not used on this machine; instead, paired hollow metal hooks (named interlacing elements) through which the warp ends are threaded, interlace the yarns into looped structure.

Darlington has enumerated various openwork and solid fabrics that may be knitted from conventional and unconventional yarns by the Waltex process. He also demonstrates that the spacing of the interlacing elements determines the machine gauge, and this is measured as the distance (millimetres) between the centres of each pair of elements in one of two parallel bearer bars. Bars with spacings of 3, 5, 7, 10 and 14 mm. are available, thus enabling more than one quality of fabric to be produced from the same machine by interchanging the bars between production runs.

Figure 2.16 illustrates five positions in one half of the loop-forming cycle:

Position (a) - the front bar is in a high position holding the loop of the back bar.

Position (b) - the front bar has swung back towards the back bar and now makes a lateral shogging motion out of the plane of the paper over the back bar element. This motion is referred to as the 'overlap' and its purpose is to place the yarn from the front bar over the back bar elements.

Position (c) - the overlap is followed by an upward movement of the back bar and a downward movement of the front bar to place the newly formed loops around the back bar elements.
Position (d) - the back bar swings away from the front bar pulling the loops it formed previously along the front bar elements.

Position (e) - the half cycle is completed with the new course of loops resting on the back bar elements.

A similar sequence of movements is then made by the back bar to form a course of loops over the front bar. If the same elements in each bar form loops around each other, then only knitted chains will be formed (see Figures 2.16). However, if a fabric is required, it is necessary to move one or other of the bars sideways, at the start of a knitting course, so that loops are formed around different elements from the previous course. This sideways movement is referred to as "underlap". Figure 2.17 illustrates a Waltex structure which is obtained by making several successive underlaps, first in one direction and then in the other.

2.6 Process Productivity

The vast range of machines, their speeds and diversity of produced fabrics outlined in this chapter above, precludes a practical productivity evaluation.

Optimum production speeds have been established after extensive production runs which may vary according to the many influencing factors. However, to facilitate some form of rational productivity comparison of the new process to some of the existing knitting processes, it seems appropriate to relate the potential of their basic loop forming mechanics (i.e. to relate numbers of loops produced in same time unit) as below:
i) It is well known that the *large multi-feed circular machines* are the fastest loop generators from the weft knitting group of machines. Several circular machines are 30 in. in diameter, fitted with 108 feeders and are capable of sustaining production of high quality jersey fabric at 18 rev/min. Thus, if a gauge of 13 needles per inch is assumed, then the number of loops made per minute is given by:

\[
\text{Number of needles in machine} \times \text{rev/min} \times \text{number of feeders} = 30 \times 3.142 \times 13 \times 18 \times 108
\]

\[= 2,381,830 \text{ loops/min}\]

ii) Applying a similar analogy to a *168 inch tricot machine* running at 1300 rev/min the number of loops produced per minute is given by:

\[
\text{Number of needles in machine} \times \text{rev/min}
\]

\[= 13 \times 168 \times 1300 \]

\[= 2,829,200 \text{ loops/min}\]

iii) Therefore, if a *Waltex type* of knitting machine running at 1300 rev/min is fitted with 13 needles per inch in each bar of 168 in. length then again the number of loops produced per minute is given by:

\[
\text{Number of needles in machine} \times \text{rev/min}
\]

\[= (13 \times 168) \times 2 \times 1300 \]

\[= 5,678,400 \text{ loops/min}\]

However, known Waltex machines would not exceed 400 rev/min.
CHAPTER 3

ORIGINATION OF THE NOVEL KNITTING SYSTEM

A knitted fabric is described as "fabric which is formed by intermeshing of loops of yarn". Any further qualifications of such fabric depend on the particular loop forming method used or on the resulting loop arrangement. In the introduction in Section 1.2, the author highlighted the possible adaptation of the earlier developed sewing-knitting technique for the purpose of speeding-up the loop forming process and possibly creating a greater variety of fabric structures in the sense of various relative loop arrangements. Consequently the investigation will be presented mainly in terms relative to existing processes and fabric structures.

3.1 Principle of the Locstitch Process

The method of producing the locked-loop pile stitch has been described in several publications but as this was the stitch from which the present research originated, it might help the reader if the cycle of operations was to be restated briefly here. Figure 3.1 shows six equal time sectional views through the stitching zone representing relative needle positions as the locked-looped stitch is formed. Also shown (Figure 3.1g) is a pictorial view of the fabric produced.

Figure 3.1a: Needle N1 pierces the base fabric and forms a loop of yarn around looper L1. Needle N2 withdraws from the opposite side of the base fabric leaving a prone loop (shown black) around the base of its pile loop (shown clear).
Figure 3.1b: Needle N1 reaches full penetration through the base fabric while needle N2 continues to retract. At this position the looper L2 traverses (shogs) by one seam pitch displacement across the point of needle N2 and parallel to the base fabric in the weft-wise direction.

Figure 3.1c: Needle N1 begins to retract from the base fabric causing a slight puckering of the yarn in the needle eye region. Needle N2 approaches the base fabric and picks up the puckered yarn from needle N1.

Figure 3.1d: Needle N1 continues to retract leaving a 'cast-off' loop around needle N2 and also leaving a prone loop (shown clear) around the base of its pile loop (shown black) to 'lock' the stitch. Needle N2 pierces the base fabric while forming a new pile loop around looper L2.

Figure 3.1e: Needle N1 continues to retract clear of looper L1 which starts to shog by one seam pitch displacement across the point of the needle. Needle N2 further penetrates the base fabric pulling the pile loop tight against looper L2.

Figure 3.1f: Needle N1 approaches the base fabric to pick up the slightly puckered yarn on needle N2 which is retracting.

The cycle is completed in Figure 3.1a: and the series of operations is continuously repeated to form the pile-fabric.

It will be noted that there is always a needle inserted into the base fabric at any one time; therefore, for a fabric to be produced the needles must move with the base fabric in the direction F whilst they are inserted and their points will each then describe a planar orbital motion. Consequently, interacting rows
of sewing type needles on each side of the fabric undergo these planar orbital motions as they cast off loops from one row to the corresponding row on the other side of the fabric, and each pile yarn serves to securely lock the other.

Additional elements and functions (such as cloth facing bars, fabric take-off means, precise yarn tensioning means, etc) are essential for a practical loop forming system. However in this context an examination of Figure 3.1g, which is a cutaway pictorial view of the basic locked-looped pile fabric, should enable the reader to conclude that if the base fabric was to be unravelled then a multiplicity of two yarn loop-chains would remain. In addition both the present author\textsuperscript{1} and Vine\textsuperscript{10} describe some locked-looped seams, where the bridging loops are pulled prone to the face of fabric, i.e. to zero pile height. The pictorial view of the looped pile fabric in Figure 3.2 shows one such seam and this further clarifies the logical basis for the initiation of this research.

3.2 The Intermeshing of Loops of Yarn to Form a 'Basic' Seam

It is clear from the preceding description and the study of Figure 3.3, that a double chain of yarns remains when the base-fabric of a Locstitch fabric has been removed. However, in the Locstitch process the base structure constrains both sides of the loop whilst the picking-up of the loop by the complementary needle is accomplished; therefore a modified process would be needed to intermesh the yarns into such a two-yarn chain structure.

The basic study began with large scale graphical three-dimensional plotting aided by large physical models of manipulating
elements and yarns. As with most textile processes, the starting-up was slightly difficult, an initial loop having to be tied in one yarn so that the other yarn could be attached. A simple gravity device was chosen to provide progression of the structure thus determining the appropriate attitude in space of the other yarn manipulating elements. The first original two-yarn chain seam was intermeshed on a simple fixture and with a pair of large wooden elements. Figure 3.4a is a photograph of one such seam, where the two different colour strings have been intermeshed, by using a similar sequence of steps to those used in the Locstitch process. A comparison of this seam with the one shown in Figure 3.4b illustrates an identical intermeshing of the two yarns. For convenience, this is referred to as the 'Basic' seam, to distinguish it from the 'Alternative' two-yarn chain seam to be described in Section 3.3. In order to gain a better understanding of the proposed method, and to provide the basis for its development, six equal-time views of the cycle of operation were drawn for producing this 'Basic' seam, Figures 3.6 to 3.12 show the needles and yarns in their relative positions when animating one complete cycle of the loop forming operations. The needles are inclined at 15° to the horizontal plane and the relative needle tip locations in simplified planar orbit are shown in Figure 3.5.

Figure 3.6: This is an arbitrary starting position (0°) where the needle $N_L$ is at its left extremity from the central fabric plane and is threaded with the lighter shaded yarn $Y_L$. This yarn is in a form of a loop $M_L$ around the needle $N_R$ and its darker yarn $Y_R$. The needle $N_R$ has passed its left extremity and it is returning along the inclined path towards the central plane.
ZERO PILE HEIGHT

FIGURE 3.2

FIGURE 3.3

(a)

(b)

FIGURE 3.4
c. The looped chain is tensioned downwards along the central plane, C.

Figure 3.7: 60° later, the needle N_L has advanced towards the central plane and the tip of this needle has passed behind the suspended yarn Y_R. It should be noted that the needle N_L is on a collision course with the needle N_R and therefore a transverse "shogging" action is required which also serves to pick-up the suspended yarn Y_R to form a new loop. The needle N_R is returning axially to the right but at relatively lower speed than the advancing needle N_L. Both running-yarns must be held at some tension to prevent the elongation of the loop M_L.

Figure 3.8: The left-side needle N_L has progressed to the right and has "shogged" transversely (i.e. towards the reader) to avoid collision with the needle N_R and to allow the suspended yarn Y_R to form a loop around the needle N_L and its yarn. Needle N_R has also progressed beyond the central plane and it is about to cast-off the loop M_L. The loop M_L envelopes the running yarn Y_R.

Figure 3.9: The right-side needle N_R has reached its right extremity (180°) and has fully cast-off the loop M_L which in turn envelopes the running yarn Y_R. The needle N_L is progressing further to the right whilst it is supporting its loop M_R. This forward progression of N_L may suitably reduce or 'set' the length of the loop M_L between points X and Z.

Figure 3.10: The tip of the right-side needle N_R has just passed in front of the suspended yarn Y_L as viewed by the reader. As with the other needle in Figure 3.7 a transverse "shogging" motion is again required to avoid collision of the needles and to pick-up the suspended yarn Y_L to form a new loop. The needle N_L is
retracting to the left, supporting the loop $M_R$ which must be cleared away from the approaching point of the needle $N_R$.

Figure 3.11: The tip of the right-side needle $N_R$ has progressed further to the left, passing between the suspended running yarn $Y_L$ and the far side of the needle $N_L$, thus forming a loop $M_L$, around its projected body cross-section. The left-side needle $N_L$ is just about to cast-off the formed loop $M_R$ which in turn envelopes the running yarn $Y_L$.

Figure 3.12: This figure ($360^\circ$) shows the two needles and their associated yarns in identical positions to those depicted in Figure 3.6, which was the arbitrary starting position ($0^\circ$), thus completing one cycle of operations. However, during this cycle, two new loops $M_L$ and $M_R$ have been formed. This formation of two loops per cycle gives rise to the prediction that at least a doubling of the production rates of warp-knitting should be possible with this novel fabric production technique (see Section 1.3 and the ensuing Sections 3.5 and 3.6).

3.3 The Intermeshing of Loops of Yarn to Form an 'Alternative' Seam

As seen by the viewer, Figure 3.7 showed the tip of the left-side needle $N_L$ passing behind the suspended pick-up yarn $Y_R$ and Figure 3.10 showed the tip of right-side needle $N_R$ passing in front of the suspended pick-up yarn $Y_L$. However if the orbits are so arranged that either both needles should pass in front of their respective pick-up yarns, or both needles should pass behind their respective pick-up yarns, then a different type of chain structure would be produced. This is here defined as the 'Alternative' two-yarn chain seam, to distinguish it from the 'Basic'
FIGURE 3.5

FIGURE 3.6
seam defined above in Section 3.2; the structure of this 'Alternative' seam will be described in Section 4.1 (Figure 4.2a).

3.4 Accuracy of Needle Closure

There is a great similarity between the cycles of operations of the Locstitch process (described in Section 3.1) and the novel knitting system (as illustrated in Section 3.2 in forming the 'Basic' seam). The predominant deviation rests with the differing attitude and control of the pick-up or running yarn.

The author and Vine described at some length the problems associated with the reliability of regular stitching in the Locstitch process, and the determining factor which influenced a clean pick-up relationship was the precise alignment requirements between each needle point and its complementary needle flank; the pick-up yarn was held adjacent to the flank of its needle by the pressure of the base fabric. However, it may be observed from the diagrams of the novel knitting cycle (see Figures 3.7 and 3.10 particularly) that the running yarn in each case is suspended from the eye of its needle to the "fell" of the chain. It is also clear that the approaching needle point should pass outside the loop held on the stem of the complementary needle. Thus a transient relationship of these constraints is shown in Figure 3.13 where the shaded triangle represents the area in which the tip of the left-side needle may securely gather the pick-up yarn. However it should be further observed that one leg of the loop is practically in the same plane as the running yarn and the triangular pick-up area. Therefore a transverse motion has to be superimposed on the planar orbital motion depicted by Figure 3.5 to fulfil all the functions of the cycle of operations. Consequently,
provided adequate time is allocated for this motion a greater reliability in performance could be expected than in the basic Locstitch process, even with wider manufacturing tolerances of the manipulating elements. The safe area in which the running yarn may be gathered is large relative to the Locstitch needle-closure conditions. However, from Figure 3.13 it is seen that only the 'eye-corner' of the pick-up triangle is positively located. The positions of the 'loop-corner' and the 'base-corner' will depend on the yarn tensions, friction conditions, and the nature of the loop formation at the base-corner. Optimisation of these constraints should provide design data for the design and construction of a reliable fabric production process.

3.5 Relative Dynamics of Loop-forming

In the introduction - (Section 1.3) a suggestion was made that two loops could be formed by the novel method during the time that only one similar loop is formed by the basic warp knitting technique. A visual assessment of the two methods may be made by a diagrammatical comparison of their respective cycles of operations.

A precise representation of a typical warp knitting cycle is hardly practicable as the types of warp knitting and their development variations are too numerous. However in all such knitting processes, the knitting cycle is a recognisably repetitive part of a continuous process in which a loop of yarn is pulled through a similar loop that has been made during a previous cycle. This entails; controlling the previously made loop, gathering and orien-
tating the warp yarn, pulling a loop of this yarn through the previously made loop and controlling the new loop for the start of the next cycle. Eyed guides and hooked needles of various designs are the mostly used yarn manipulating elements.

The latch-needle Raschel type process is used here as a basis for comparison, since the number of used elements is small and the manipulating paths are relatively simple and dimensionally similar to those of the novel process. Figure 3.14 (a and b) illustrate an approximate locus of the latch-needle hook and its associated guide-bar respectively on a typical warp-knitting machine. The needle's rise and fall paths are coinciding as in pure reciprocation, but the path of the eye of the guide needs to be orbital and in a plane which is transverse to the needle path. It may be further assumed that the motions are generated by cranks (i.e. modified S.H.M) without dwells, thus resulting in the lowest accelerations and their associated forces. Figure 3.14c shows the approximate curves of needle and guide displacements and accelerations for a warp knitting machine running at 1000 cycles per minute.

Similar assumptions for needle motions may be made for the novel method, except for the transverse or shogging motion. The author used crank motions to generate both the primary and secondary motions on the original Locstitch research rig (both with crank-connecting rod ratio modifications). However the shogging motion in this novel process should be of relatively shorter duration than a full cycle, thus necessitating a cam motion. The approximate locus of the two needle tips are shown in Figure 3.15 (a and b). The curves of displacements and accelerations of
FIGURE 3.14c

YARN GUIDE

LATCH NEEDLE

FIGURE 3.15 c

L.H. NEEDLE

R.H. NEEDLE

DISPLACEMENT
ACCELERATION
needle tips at 1000 cycles per minute are plotted in Figure 3.15c.

It should be reasonable to assume that the reciprocating and oscillating masses would be of similar magnitudes for both the processes being compared. Therefore the acceleration curves in Figures 3.14c and 3.15c may be compared directly. Their magnitudes are similar and hence the inertia forces will also be similar in magnitude. The dynamic behaviour of the knitting needle latches is complex and is often a limitation to the optimum running speeds of latch-needle type machines. Eyed needles are envisaged for the novel method, thus removing this potential limitation of running speed. This comparative assessment is used to predict that the cyclic running speeds of the projected designs of machines, based on the novel method, should be at least as fast as the fastest warp knitting machines, whilst producing two stitches per cycle instead of the conventional single stitch. However, the directions of the forces are diverse and careful balancing of the machines will be essential.

It may be relevant to indicate here that the bearded-needle Tricot machines were not used in the above comparison of dynamic motions, because of their additional presser-bar movement and the much more intricate locus of the needle hook.

3.6 Potential Production Speeds

In the previous section it was shown that in the novel method the yarn manipulating elements should be capable of withstanding machine speeds similar to those of warp knitting machines. However the optimum productivity of all yarn-using machinery (e.g. knitting and weaving) often depends upon the tolerable stresses
experienced by the yarns during the fabric-forming cycle. Stresses of yarns are usually calculated from supply yarn tension measurements, since to measure true yarn stresses that occur during 'back robbing' and loop setting is difficult.

At this stage in the development, a diagrammatical comparison of the yarn manipulation as observed in Figure 3.14 and Figure 3.15 should suffice. It appears that in the novel knitting method, slightly more yarn should be back-robbed for control of the stitch length and its uniformity than is necessary in the warp knitting process. However, during stitch formation by the warp knitting process, successive loops of yarn are subjected to full rubbing friction between themselves on both sides of the hook of the needle. On the novel knitting it is feasible to shield, at least, the feed-side yarn with a suitable groove in the face of the needle. Thus, on balance, no reduction in loop-forming rates should result.

It is well known, that in productivity comparisons of knitted goods, the machine speeds, or courses produced per unit time, are effective for a particular type of process only. A more representative comparison of process productivity is obtained by relating the number of similar loops produced per unit time. In consequence the relative productivity of the novel knitting should be at least double to that of comparable warp knitting since two loops are produced per cycle.
CHAPTER 4

LARGE-SCALE GRAPHICAL STUDY OF SOME
POTENTIAL FABRIC STRUCTURES

The 'Basic' loop forming cycle of operations of the novel
method, was outlined in Section 3.2 and the modification of this
cycle to form an 'Alternative' seam was described in Section 3.3.
Successive continuation of such cycles of operations would produce
chains of loops which are products in themselves for novelty
effect yarn purposes (see Sections 1.2 and 4.1). However, it was
anticipated that, as with other loop-forming fabric production
techniques, the novel method would also be capable of generating
a range of structure variants. Consequently a clearer apprecia-
tion of its adaptability was necessary, to provide some guidance
for the necessary design features of the rig for experimentation.

All the following diagrams show the yarns and loops to an
approximate enlargement of 10:1. The yarns are differently shaded
to ease the tracing of their continuation. Only the lapping order
of the yarns is precise, the curvatures and the attitudes of loops
relatively to the viewing plane are approximate so as to assist
the legibility of the diagrams.

4.1 The Single Seam as a Novelty Yarn Structure

Figure 4.1a illustrates a looped chain of two yarns. This
chain would result if the yarns were manipulated in a continued
sequence according to the orbits shown for producing the 'Basic'
seam as designated in Section 3.2. It will be recalled from the
illustrations depicting the Novel knitting cycle in Section 3.2,
that the right-side needle passes in front of the suspended pick-
up yarn Y_L as seen by the viewer in Figure 3.10, and the left-side
needle passes behind its pick-up yarn $Y_R$ as seen by the viewer in Figure 3.7. This arrangement places yarn portions 1, 2 and 3 alongside one another across the short leg 4 of all loops, as shown in Figure 4.1a.

Varied tensions and different yarn characteristics would vary the attitudes and curvatures of the loops, but the order of overlapping or underlapping of the two yarns must remain the same. The actual structure would be three-dimensional unless the loops were set into one plane as shown diagrammatically in Figure 4.1a.

Speciality effect yarns (e.g. chainette and mock-chenille) are used because of their increased bulk and novelty in appearance. The bulk of such chains may be varied with the singles yarn counts and with the setting of the loop lengths. The novelty appearance of such two-yarn chains would be enhanced with the freedom to select two very different yarns. Coupling this to potentially higher producing rates could create a new market for such novel products.

Chain structures made from either one yarn (on the Raschel principle) or two yarns (using the novel technique) would be relatively unstable if they were made under low yarn tensions. Better stability and improved loop size control should be aided with the laid-in warp 1 in Figure 4.1b or warps 1 and 2 in Figure 4.1c. These warps could be laced into the chain on every looping cycle, as shown, or selectively, according to the capability of the producing system, thus further widening the variety of envisaged products.

In the manufacture of elasticised or stretch materials the elastic yarns are often individually covered with braided or looped
covering. This covering limits the elongation and recovery of these elastic yarns and thus materials may be designed to meet particular requirements.

If the warp 1 in Figure 4.1b were to be replaced by an appropriately stretched elastic yarn and the chain loops were suitably tightened, then this could result in an alternative, probably more rapidly-covered, elastic yarn.

All the above looped chain structures have resulted directly from the cycle of operations as to produce the 'Basic' seam as described in Section 3.2; however, if both needles should pass either in front of, or behind, their respective pick-up yarns, then a different type of chain is produced and this has been defined as the 'Alternative' seam in Section 3.3.

Figure 4.2a illustrates the 'Alternative' seam and it may be observed that only two yarn portions 1 and 2 lie alongside each other and across the short leg of loop 3. This relationship of yarns in the chain is true, provided the loops remain open as shown in the illustration. Again warp 1 may be laid-in as shown in Figure 4.2b, and similarly warps 1 and 2 as in Figure 4.2c; subject to the versatility of the machine, the warps may be laid-in with the chain on every looping cycle or selectively, to suit the requirements. Similar reasoning of the suitability of the process should again apply to the covering of elastic yarns as described in the immediately preceding paragraph.

The differences of the loop arrangement in the chains, i.e. between the 'Basic' and 'Alternative' seam structures, may appear to be insignificant for novelty effect yarn constructions. However the ensuing sections of this chapter will show that fabric
FIGURE 4.2
constructions are more markedly different when the two seams are contrasted. Moreover, the design parameters of any prototype test-rig would be severely affected by the range of seam-types to be produced since extra mechanisms would be necessary.

4.2 Pillar-Seams Connected by Weft Lays

In the previous section it was shown that repeated cycles of the twin-yarn knitting would produce looped chains extending in the warpwise direction. If neck chains were produced simultaneously on a plurality of adjacent elements and were interconnected with each other, a textile fabric would result. Straight wefts could be laid-in on the left-side of the 'Basic' chains at about the arbitrary starting position as shown in Figure 3.6. Similarly on the right-side of the chains the laying-in may occur, 180° later in time, and as shown in Figure 3.9.

Figure 4.3a shows the edge view of the fabric where the straight wefts are seen end-on. The face view of the fabric is shown in Figure 4.3b. The wefts 1 appear on the near side of the fabric and the darker wefts 2 are visible on the near side. Such a fabric would be stable in the weft direction, but the pillar seams could possibly slide along the wefts, thus causing an irregular appearance.

Straight warps could also be laid-in as shown in Figures 4.4a and b. The resulting fabric would be highly stable in both the weft and warp directions. However the diagonal stability of the fabric would depend upon the wale and course densities, and it would probably have somewhat similar characteristics to woven fabrics.
FIGURE 4.3

(a) 
(b) 

FIGURE 4.4

(a) 
(b)
The 'Alternative' looped chains (Figure 4.2a), which could be produced by the alternative looping sequence as described in Section 3.3, could also be similarly connected to form a textile fabric, as in Figure 4.5. The physical characteristics of such fabric should be closely similar to those of the fabric described immediately above, yet the appearance of the fabric faces would be substantially different as may be observed by comparing Figure 4.4 with Figure 4.5.

4.3 Pillar-Seams Connected by Warp Lays

A different fabric structure may be made by connecting the pillar-seams with additional yarns that progress generally in the warp direction. These yarns may be laced-into the chain during a similar period in the cycle to that described above in the introductory paragraph of Section 4.2. There is a fairly wide variety of possible lacing patterns and these will be progressively described below:

Figure 4.6 illustrates, in two views, a fabric in which a warp yarn is laced into the adjacent chains from one side of the fabric on successive courses of knitting. The orientation of the chains and the lacing warps are shown in the unstrained relationship. Any exerted external pull, or even the presence of internal bending strains on release from the manipulating elements, would distort the appearance of this fabric from that which has been conveniently illustrated.

The chains may also be laced together with warps from both sides of the fabric as in Figure 4.7. In this pattern of lacing each chain-loop is laced to one or other of the adjacent chains on
successive courses.

Figure 4.8 shows a fabric in which the chains are laced to both adjacent chains on one side of fabric only. Assuming similar warp tensions, this arrangement is very nearly symmetrical in both planes and its structure ought therefore to be better balanced than the previous two examples.

Figure 4.9 shows a fabric in which the loops are laced to both adjacent chains on both sides of the fabric. Such fabric, if made from the same yarns and with similar tensions, would be of identical appearance on both front and rear faces.

All of the above warp-lacing variants could also be designed with the next-but-one chains being laced together instead of the lacing of immediately adjacent chains. Only one such fabric is shown in Figure 4.10 for reasons of economy in the number of illustrations used.

Similarly it may be assumed that other such warp-lacing variants are possible if connection is obtained both ways across 'next-but-two' chains, one such fabric being shown in Figure 4.11.

Figure 4.12 illustrates a fabric where the warp-laced chain may be selected by some form of pattern control device. Again it is thought to be reasonable to suggest that the selection could apply to all the above mentioned lacing variants. However, once a particular warp movement direction has been selected, then this movement would naturally apply to all the warp yarns in that particular bank.

Further fabric variants would arise from this warp-lacing technique if the lacing warps were varied in type and the selected mode was different on the two fabric faces.
THREE-CHAIN LACING

LACING WARPS

FIGURE 4.11
The fabrics described so far in this 'warp-lacing' section have all been based on pillar seams of the 'Basic' chain seam type which was illustrated in Figure 4.1 and defined in Section 3.2. If it is accepted that the 'Alternative' chain seam, shown in Figure 4.2 and defined in Section 3.3, is sufficiently different from this 'Basic' type chain seam, then it must follow that fabrics made by warp-lacing such 'Alternative' pillar seams would also appear different. Figure 4.13 shows an example of a warp-laced fabric where the chains are of the 'Alternative' type and this should be compared with the fabric shown in Figure 4.8. The two fabrics appear substantially different in that fabrics made from the 'Alternative' chain seam would not appear alike on the two faces even if the lacing warps and the modes of lacing were identical. Moreover, there does not appear to be any reason why all the above mentioned lacing variants which are incorporated in the 'Basic' chains as the pillar seams should not equally apply to fabrics with a corresponding use of the 'Alternative' chains as the pillar seams; in all these cases the appearance of the fabrics should exhibit discernible differences.

All the above types of warp-laced structures may be made denser and more stable by laying-in straight wefts and/or straight warps. One such structure is shown in Figure 4.14, which happens to be based on the 'Alternative' type pillar chain seam. All such fabric structures would have different appearances and their physical characteristics would also vary.

A general criticism of these warp-laced fabrics, and particularly the last mentioned types which incorporate extra weft-laying and/or warp-laying, is obviously that they use great amounts of yarn, and except where fabric weight is important this is undesirable.
Similar criticisms were levelled at the Co-We-Knit machine when it was introduced in 1968. The next section will therefore discuss the possible intermeshing of the chain seams themselves which should make for economies in yarn usage.

4.4 Loops intermeshed with Adjacent Wales

The cycle of operations of loop formation is described in Section 3.2, where only one pair of needles are manipulating two yarns into the 'Basic' looped chain. If, provided that there are more than three pairs of needles with their associated yarns, then this should permit the generation of an interlaced fabric structure, without necessarily using additional yarns. Figure 3.5 illustrates the two loci of the needle tips which are substantially planar. It may be observed that the left-hand needle NL is in open space between the timing points 300° and 60°. Thus, in this space and timing region, a suitable mechanism could displace this needle tip transversely, say one pitch, without deviating from the locus as shown in Figure 3.5. Therefore loops should be formed in the usual manner, yet when viewed in the direction of the needle movement, the loops would be seen to be laced into a neighbouring wale.

Alternating the direction of this transverse displacement on successive cycles, would retain a warp-wise progression of the loop intermeshing and thus a rectangular sheet of fabric would be made. Figure 4.15 illustrates a 'Basic' chain structure, where both needle banks shog relatively to one another, by one wale pitch in alternate directions on successive loop forming cycles.

Should dynamic conditions permit, then shogging may occur over two wale pitches as in Figure 4.16, or even over three or
more pitches. This shogging of the needle banks may be operated selectively, to a required design, as shown for instance in Figure 4.17, provided that, over the total time period allowed, the nett shogging in both directions is zero.

The seam interlacing, as described above for the 'Basic' chain seam, should apply similarly to the 'Alternative' method of forming a chain and consequently the range of generated structures would be doubled. Only one such structure of one-wale shogging of the 'Alternative' seam is illustrated in Figure 4.18, for comparison purposes with Figure 4.15. Here it must be emphasised, that all loops of the yarns have been drawn in positions as traced by the manipulating elements. Consequent back-robbing and tension equalization would reshape the curvatures and slopes of the loops, although the basic structures will be retained.

4.5 Loops Intermeshed with Adjacent Wales and Weft Lays

The fabric structures, as described in Section 4.4, appear to be the most similar to conventionally knitted fabrics. As with such knitted structures they have a low resistance to stretching in the weft direction particularly.

From a consideration of the cycles of the loop forming operations for the various structures, it appears that additional wefts (as in Section 4.2) may also be introduced for these loop-intermeshed structures. Figure 4.19 illustrates one such laterally intermeshed fabric structure, which is based on the 'Basic' chain-forming principle, with the extra inclusion of stabilizing weft lays. A structure resulting from the alternately-lapped looping sequence is also shown in Figure 4.20. Both structures are shown
with inserted weft-lays from both sides of the fabric, i.e. two weft insertions per complete cycle. It may also be visualised, that for each of these structure variants, the weft-lays could be inserted from one side of the fabric only.

Further extensions to the structure range would result from a variation of the weft insertion frequency by controlled weft selection and/or the use of multi-coloured wefts. These would thus appear as striping effects as well as exhibiting improved fabric stability and increased fabric density.

4.6 Loops Intermeshed with Adjacent Wales and Warp Lays

Using continuity of line as the main constraint, two forms of warps may be graphically superimposed on all the loop-intermeshed fabric structures previously described in Section 4.4. Figure 4.21 shows warps which are laid-in between the wale loops. These warps are conveniently illustrated as straight yarns and are shown as 'covered' by the intermeshing yarns. However, subject to high loop setting tensions, the warps would probably be distorted into a wave form normal to the plane of the fabric, similar to the warp path in a loosely woven cloth. Such laid-in warps may be positioned between each successive wale of loops, as shown in the Figure 4.21, or alternatively in preferred pillar forms of warp stripes.

Within the basic structures, warps may also be laid-in in a form of a wave lying within the plane of the fabric. The amplitude of this wave may envelope one, two or more wales. The frequency of the wave may be the same or lower than the loop forming frequency. All these warp lays are graphically feasible, for either the 'Basic'
FIGURE 4.20

STRAIGHT WARPS

FIGURE 4.21

STRAIGHT WEFTS
or 'Alternative' loop-forming methods, but for simplicity only the composite waveform is illustrated in Figure 4.22. There could also be a 'composite' waveform, comprising 2 warps in 'anti-phase', interlacing with the same pillar seam as shown in Figure 4.22. This could result in a more stable structure due to the balancing of warp tensions.

Again, all the warp lays described in this Section could be graphically feasible for either the 'Basic' or 'Alternative' loop-forming methods.

4.7 Loops Intermeshed with Adjacent Wales and both Weft and Warp Lays

The study to date suggests that all the fabric structures which have been hitherto mentioned in this Chapter 4 may be graphically combined into even more complex fabrics; therefore, to complete the separate groupings of the main fabric variations, one such structure, that includes both weft and warp lays in a loop-intermeshed structure is shown in Figure 4.23. This structure contains wefts and the simpler straight warp lays only and would be expected to possess rather similar weft-wise and warp-wise stability to a loosely woven fabric.

4.8 Summary.

A very wide variety of graphically possible textile structures has been described in this Chapter. It now remains to investigate how many of these variants can be accomplished on the necessarily limited capabilities of a powered experimental rig and these will be discussed in Chapters 7 and 8. Meanwhile, further consideration
of some of these structures could be aided by the use of Computer Graphics (Chapter 5) and Large-Scale Modelling (Chapter 6).
CHAPTER 5
THE USE OF COMPUTER-AIDED GRAPHICS IN THE
INVESTIGATION OF FABRIC STRUCTURES

Following the conception of the novel loop forming principle, a rapid study of its adaptability and versatility in probable fabric structuring was essential. Hence, in parallel with the large scale graphical study (as described in Chapter 4) the use of an existing computer-aided topology was considered. However, it was soon apparent that a suitable programme was not yet available, thus rendering this attempt impracticable.

Other aids were considered and a computerised drawing routine was adapted to speed-up the repetitive drawing of loops and to improve the visualisation of some potential fabric structures.

5.1 The Single Seam as a Novelty Yarn Structure

5.1.1 The 'Basic' Seam

Using the arc and line drawing routines of the 'GINO' system\textsuperscript{12} (coupled to the computer\textsuperscript{13} of Loughborough University) the centre lines of the 'Basic' looped chain of the yarns were defined and prepared in a spatial coordinate programme (see Appendix 1).

The description of this rather complex path was laborious, but the viewing and scaling routines were rapid and useful. Figure 5.1a illustrates a computer drawn face view of the 'Basic' seam, each yarn being represented by a single line. The line is shown continuous for the yarn introduced from the rear of the structure, and a dashed line is shown to represent the yarn introduced from the front of the structure. It is relatively simple to trace the path of each yarn, but there is no easy separation of over-lapping
FIGURE 5.1
or under-lapping of the yarns. The scale adapted for this drawing is approximately the same as that used for the looped-chain drawings in Section 4.

The repeat accuracy and convenience of these drawings is good, but their appearance would be enhanced by using a greater line thickness, which could be easily achieved with a broader plotting-pen. It is also feasible to calculate the theoretical loop distortions, due to nominal values of loop setting tensions relative to the loop lengths and the yarn flexural rigidity. Such analysis, however, would be extensive in time and cost and could not be justified at this stage of the process development. A further useful feature accrues from viewing the chains from other directions; thus Figure 5.1b is a side or edge view of the 'Basic' chain (Figure 5.1a) when viewed in the direction of the arrow. This view may be read as an orthographic left-hand side view in the 'First Angle Projection System', which is the basic convention of Engineering Drawing. This side-view should also correspond to the manually drawn 'Basic' seam previously shown as Figure 4.1a. However, for reasons of clarity in the drawing of over-lapping and under-lapping of the yarns, this latter seam was shown as 'flattened', thus resulting in a relatively more distorted appearance than the projected computer-drawn view of Figure 5.1b. Figure 5.1c shows the same chain in an isometric pictorial view. Such views proved useful for the all-round visualisation of the novelty-effect chainette yarns and covered elastic yarns during the feasibility study stages of this development.

An easy change of the scale of the drawings was another useful gain in the visualisation of the conceived structures. Thus Figure 5.2 shows the same three views of the chain drawn to the scale 1:2 from the size of the loops previously used in Figure 5.1, and Figure
FIGURE 5.2

FIGURE 5.3
5.3 shows the same chain to the scale 1:5, this latter drawing appearing similar in size to an actual-size coarse chainette yarn. The physical 'bulk' of such chainette structures can be more easily appreciated, because the line thickness is also more closely reflecting an actual sized view of a yarn. However it becomes more difficult to trace the paths of the two separate ends of the yarns, as the resolution of the dashes and spaces, at the smaller scale, becomes less discernible. Figure 5.4 shows three computer-drawn views of a 'Basic' seam which incorporates an inlaid warp (corresponding to the one such manually drawn seam previously illustrated in Figure 4.1b). Again Figure 5.5 shows the same three views of the seam to a scale 1:2 and the Figure 5.6 shows them to a scale 1:5; this latter scale, however, is representing the lines of loops to a size that appears to be natural for such speciality-effect yarns. If, in such a 'Basic' seam, the inlaid warp-yarn were to be replaced by an elastic latex yarn at a suitable tension, then this structure would result in a 'covered elastic yarn'. Such elastic yarns could be used in the manufacture of some types of decoratively-covered elastic bands (e.g. hair-bands, arm bands, etc) and stretch-fabrics. The extensibility of covered yarns can be closely controlled and thus the elastic characteristics of fabrics made from these yarns could be predicted and maintained.

5.1.2 The 'Alternative' Seam

Although the looping cycle which produces the 'Alternative' seam differs little from that which produces the 'Basic' seam (as was described in Section 3.3), the programme of computer drawing instruction is substantially different. A copy of this programme is given in Appendix II, for comparison with the programme for drawing the 'Basic'
FIGURE 5.4
FIGURE 5.5

FIGURE 5.6
Figure 5.7a shows a computer drawn 'face-view' of the 'Alternative' seam. As with the corresponding drawing of the 'Basic' seam (Figure 5.1a) this is a direct front view where a continuous line is used to represent the yarn which is introduced from the rear of the structure and a dashed line is used to represent the yarn which is introduced from the front of the structure. A visual comparison of the two 'face-views' clearly illustrates the difference in appearance between the 'Basic' and the 'Alternative' seams.

Figure 5.7b is a side or edge view of the 'Alternative' seam which is viewed in the direction of the arrow X in Figure 5.7a. This view is not very helpful when it is compared to Figure 5.1b as without the differentiation of visible and hidden lines the two chain-seams appear to be similar. However, the isometric view of the 'Alternative' chain-seam, illustrated in Figure 5.7c, is more informative as the continuity of both yarns may be traced more easily. It may also be observed that the loops are drawn to correspond with their immediate attitudes as they are manipulated by their elements, and it would be expected that, in practice, chain-seams made from resilient yarns would appear substantially different. Some curves, for example at p and q in Figure 5.7c, would straighten-out after their release from the constraining elements.

Figures 5.8 and 5.9 illustrate the computer-drawn 'Alternative' chain-seam to scale 1:2 and scale 1:5 respectively. Again the isometric views (Figure 5.8c and Figure 5.9c) appear to be more informative than the other views, and the smallest scale isometric drawing permits a nearly-real-size visualisation of the 'Alternative' chain seam.
FIGURE 5.8

FIGURE 5.9
Figure 5.10 illustrates the computer-aided drawings of the 'Alternative' seam with warp-in-lays.

5.2 Pillar Seams Connected by Weft Lays

Having started with the computer aided drawing of the simplest structure, i.e. the chain-seam or the pillar-seam as in Chapter 4, it appears to be beneficial to extend the graphical study into a similar range of projected structures. A clear graphical appreciation of complex structures should lead to later savings in often lengthy and expensive experimentation.

5.2.1 The 'Basic' Type of Structure

Repeating the computer drawing routines of the 'Basic' seam (Section 5.1.1) for five parallel pillar-seams, and introducing straight lines to represent the connecting weft-yarns, a face view of the structure is drawn. Figure 5.11a shows one such structure which corresponds to the manually drawn weft-lay structure of Figure 4.3b. By comparison the manual drawing appears more natural as the yarn thicknesses are shown to better proportions and more importantly the 'over-lapping' and 'under-lapping' of yarns is more clearly shown.

Figure 5.11b is a left hand side view of this structure. When superficially examined this projection appears to be different than its equivalent drawing in Figure 4.3a, but it will be recalled (from Chapter 4) that, for reasons of clarity, the manually drawn edge-views of the seams were shown 'flattened' rather than as now shown in direct projection.
FIGURE 5.10
Figure 5.11c shows a 'Basic' type weft-laid fabric projected pictorially, but omitting the effects of perspective. This again is a more informative view than a direct 'face-view' and the computer-aided drawing is achieved by a relatively simple viewing routine. Two weft yarns are shown per full looping cycle, a continuous line representing the weft-yarn, introduced from the front of the fabric, and a dashed line representing the other weft-yarn introduced from the rear. A closer examination of the front and side views, Figure 5.11a and Figure 5.11b respectively, suggests that the same weft-yarn may be introduced at two weft-lays per one cycle of the operations.

Figure 5.12(a, b and c) illustrates the 'Basic' type weft-laid fabric in front-view, side-view and a pictorial-view respectively but to a scale of 1/2 from the original drawing, and the same three views are shown to scale 1:5 in Figure 5.13. The three views in Figure 5.13 are approximately of real-size and the reader may visualise, from such drawings, the potential density of the structure.

Eventually a programme could be developed to predict the yarn content of such structures, but such a programme would have to correct the curvature and the attitudes of all the loops, relatively to the yarn and fabric characteristics.

5.2.2 The 'Alternative' Type of Structure

Using the subroutine for computer-aided drawing of the 'Alternative' type pillar seam from Section 5.1.2 as a building block, and superimposing the transversely drawn lines to represent the connecting weft-yarns, a complete drawing programme can be arranged.
Figure 5.14(a, b and c) illustrates the face-view, edge-view and a pictorial view of the resulting drawings at an enlarged scale which was selected at random to ease the detailing of the yarn-chains. The same three views of this structure are shown to 1:2 scale in Figure 5.15 and 1:5 scale in Figure 5.16.

5.3 Pillar-Seams Connected by Warp-Lacing

The next simplest form of structure results from lacing together the pillar-seams by yarns which progress primarily in the warp direction. From purely graphical considerations there is no limit to the number of seams that this warp-lacing may embrace (see Section 4.3) and substantial visual appreciation of the varied projected drawings has been gained; however, for reasons of conciseness, only one typical example of each group of structures is included in this thesis.

5.3.1 The 'Basic-Type' Structure

Figure 5.17a shows the face-view of the simplest warp-laced structure, i.e. each pillar-seam is laced to both its neighbouring seams by two laces on each complete looping cycle. It may be observed that such fabric should exhibit similar stability in both warp and weft directions. Figure 5.17b is an edge-view and Figure 5.17c is an isometric-view of the structure to the same enlarged scale.

Figures 5.18 and 5.19 show similar views of the same structure to scales of 1:2 and 1:5 respectively.
FIGURE 5.14

FACE VIEW (a)

EDGE VIEW X (b)
FIGURE 5.17

FACE VIEW
(a)

EDGE VIEW X
(b)
FIGURE 5.18

FIGURE 5.19
5.3.2 The 'Alternative-Type' Structure

Again, from purely graphical considerations, a large range of warp-lacing variants are feasible. The computer-aided drawing in Figure 5.20(a, b and c) illustrates a structure, where the 'Alternative-Type' pillar seams are laced to their immediate neighbouring seams at each loop interaction (similar to Figure 5.17 for the 'Basic-Type' structure). Comparison of the two types of the structures suggests that the 'Alternative-Type' structure may be less well-balanced due to the unidirectional inclination of the front and rear bridging loops. Figure 5.20a shows this structure in a direct face-view, the Figure 5.20b is an edge-view of the structure if projected in the direction of the arrow X from Figure 5.20a and Figure 5.20c is an isometric view. Figures 5.21 and 5.22 show the same three views of the structure to scales of 1:2 and 1:5 respectively.

5.4 Loops Intermeshed with Adjacent Wales by Bridging Loops

This third major group of structures (see Chapter 4) should result, when either both banks of needles or only one bank of needles move to interact with their neighbouring complementary needles. Again the probable range of intermeshing and filling-in with additional yarns is large, although for conciseness only one example of both types of structure is given here.

5.4.1 The 'Basic-Type' Structure

Figure 5.23a shows a computer-aided drawing of a face-view of a 'Basic-Type' structure in which all the bridging loops are laced into their neighbouring wales, alternatively to the right wales and
FIGURE 5.20
FIGURE 5.21

FIGURE 5.22
and to the left wales on successive cycles on both sides of the structure. It is evident from an examination of Figure 5.23a that a substantial reorientation of loops would result once the actual structure was removed from the yarn manipulating elements.

Figure 5.23b shows an edge-view of the structure which is projected from Figure 5.23a in the direction of the arrow X. This view of the structure would have a similar reorientation of the loops and their curvatures on relaxation of external forces as in the face-view above.

An isometric view of this structure is shown in Figure 5.23c. Different viewing positions clarify an alternative aspect in visualisation of potential merits of the structure variant.

The same three views are shown in Figures 5.24 and 5.25 to reduced scales of 1:2 and 1:5 respectively.

5.4.2 The 'Alternative-Type' Structure

The concluding example of the structure groups is shown in Figures 5.26, 5.27 and 5.28. As before the Figure 5.26a shows the computer-aided drawing of the face-view of the 'Alternative-Type' structure, the Figure 5.26b is an edge-view of the structure and the Figure 5.26c is an isometric projection of the same structure. Figures 5.27 and 5.28 repeat the same three views of the structure to reduced scales.
FIGURE 5.23

FACE VIEW (a)

EDGE VIEW X (b)
FIGURE 5.27

FIGURE 5.28
CHAPTER 6

LARGE-SCALE MODELS OF NOVEL STRUCTURES

There is a very large range of graphically conceivable structures that may be associated with the twin-needle system as could be seen from the drawings in Chapters 4 and 5. However, it is difficult to assess the potential of most of these structures from mere drawings and it is even more difficult to define the design parameters of the manufacturing machinery from such graphically depicted structures. Thus, as a natural progression in this development, several large eyed needle elements were made and, using simple wooden frames and coarse rug-wool of different colours, most of the aforementioned structures were made manually as large-scale model fabrics. The difficulties and peculiarities of the yarn manipulations were observed and noted, together with some assessments of fabric stability, density and weight.

The model structures were each investigated and are presented here in the sequence adopted for the treatment of the graphical structures in Chapters 4 and 5.

6.1 The Single-Seam as a Novelty Yarn Structure

Figure 6.1 is a photograph of the simple apparatus used for making the large models of the single-seam structures. The wooden needles (1 and 2) are similar to the needles used by the author in the previous investigation, i.e. eyed-needles similar in appearance to sewing machine needles but made to scale of approximately 10:1. The loops are generated upwards by manually tracing the paths of the needles, as proposed in Section 3.2 in relation to a point (3), to which the fabric is attached. The course-running yarns (4 and 5)
FIGURE 6.1
pass through eyelets (6 and 7) and the yarns are tensioned by means of dead-weights attached to their running ends. In making the loop sizes are controlled by holding the needles at an appropriate distance from the point (3), however the eventual loop forms and their density is dependent upon the tension induced in the yarns by the dead weights, the progression of the needles from the point (3) and the protrusion of the needles through the loops.

6.1.1 The 'Basic' Seam

Using green wool yarn in the right needle (2) and yellow wool in the left needle (1), and manipulating the needles as previously described in Section 3.2, a coarse 'Basic' chain was produced. The photograph (Figure 6.2a) illustrates a face view of the chain, i.e. a view along the right-side needle, and Figure 6.2b illustrates an edge view of the chain (a view of the chain which is also seen in the centre of Figure 6.1).

Apart from the difficulty of maintaining similar loop sizes, the outlined manipulation technique appears to be correct in principle. Relatively to the equivalent graphically drawn chains in Figures 4.1a and 5.1 (a and b) the order of overlapping and underlapping of the two yarns is correct. The 'bulk' and the general appearance however varies substantially due to the resilience and cross-sectional packing density of the woollen yarns.

Repeating the procedure as above and soliciting the assistance of an extra pair of hands for laying-in two additional warps, the photograph of the resulting chain is shown in Figure 6.3(a and b). Again this chain corresponds to the chains drawn in Figures 4.1c and 5.4(a and b).
FIGURE 6.2

FIGURE 6.3
The bulk and extensibility of such a chain may be easily varied by applying appropriate tensions to the inlay-warps and the setting of loop sizes. However the laying-in of the warps is difficult, even by hand, and this must be noted as an important design parameter of the projected machinery.

As a further variant to the single 'Basic' seam, an elastic band was laid into the chain in place of the two warps. The elastic band was laid into the chain at a strain of 25% approximately and the structure at this length is shown in Figure 6.4a. Figure 6.4b shows this chain, or 'covered-yarn' fully relaxed (which is of the same length as the original length of the elastic band). The 'covered-yarn' is fully extended in Figure 6.4c and this exhibits a strain of approximately 60% relatively to the relaxed length. The same elastic band, when unconstrained, sustains a strain of more than 200%. Such strain constraint characteristics may not be usable in practice, but it amply demonstrates, at least on this large scale, that this covering structure is effective for the strain control of elastic yarns.

6.1.2 The 'Alternative' Seam

Using the same coloured rug-wools, and similar loop sizes, the 'Alternative' chain seam was made by animating the operational cycle that was described in Section 3.3. The photographs of the face-view (Figure 6.5a) and the edge-view (Figure 6.5b) were taken from the same positions as for the 'Basic' seam above to ease the reader's task in comparing the seams.

The 'Alternative' seam with warp in-lays is shown in Figure 6.6(a and b). The differences between the 'Basic' seam and the 'Alternative' seam appear to be less noticeable than was seen in
FIGURE 6.5

FIGURE 6.6
the graphically drawn diagrams of Sections 4.1 and 5.1, mainly
because the chosen loop sizes together with the bulky rug-wool
hide the rear yarns in both views. The level of difficulty in
animating the warp in-laying however is substantially the same
as it was in the case of the animation of the 'Basic' seam.

Surprisingly, the strain-constraining characteristics of the
'Alternative' type covered yarns were shown to be substantially
different. Consequently, several models were made and Figure
6.7(a, b and c) illustrates a typical example. Figure 6.7a shows
the 'Alternative' covered-yarn at 25% strain (which is the strain
during the manufacturing) and the Figure 6.7b is the same yarn
fully relaxed. The fully extended yarn is shown in Figure 6.7c,
which is approximately 80% longer than its relaxed length.

6.2 Pillar Seams Connected by Weft-Lays

For making the multi-seam structures, two banks of 7 large
wooden needles were constructed and used in conjunction with a
simple stand, as shown in Figure 6.8. The eyes of these needles
were rotated through 90° relatively to the attitude of the eyes of
the needles, which were shown earlier in the diagrams appertaining
to Section 3.2. This changed attitude of the needle eyes appeared
to be advantageous for picking-up of the 'suspended-yarn' on both
sides of the needle point.

The pitch spacing of the needles was set to approximately the
same distance as had been used in the large scale drawings (Chapters
4 and 5). Such a close spacing however necessitated the relieving
of all needle shanks to permit penetration of the one needle bank
by the other needle bank, which had been previously suggested, as
an essential requirement in the cycle of operations in Section 3.2.
6.2.1 The 'Basic-Type' Structure

The practicability of the looping cycle for producing a pillar-seam was outlined in Section 6.1. Repeating such a cycle manually with banks of 7 needles in each bank is substantially more cumbersome, but it appears to be very practicable to be designed into a mechanical system. However, laying-in the connecting weft yarn is easy in this narrow width and slow cycle time, but it would be very difficult to achieve with practicable working widths and high running speeds.

The model structure of the 'Basic-Type' (pillar-seams connected by weft-lays) is shown in Figure 6.9. The green yarns are introduced by the front needles and the yellow yarns by the rear needles. The black and the white weft yarns are laid-in from the front and the rear of the structure respectively.

For this structure the weft-size stability is dependent entirely upon the characteristics of the weft yarns as the wefts are practically straight. However if the packing density of the pillar seams is low, then these may be easily bunched-up and the structure may appear to be laddered as shown at (1) in Figure 6.10.

The warp-wise stability is provided only by the loops of the pillar-seams and therefore it is relatively low. Additional warps may be laid-in between the pillar seams, as was outlined in Section 4.2. One such example with laid-in red coloured warps is shown in Figure 6.11. These additional warps are laid-in easily and provide good stability in the warp direction of the fabric. Moreover, they fill-up the space between the pillar-seams and reduce their tendency for bunching-up.
FIGURE 6.9
6.2.2 The 'Alternative-Type' Structure

Figure 6.12 illustrates the 'Alternative-Type' structure made from rug-wools of the same colouring as in the case of the 'Basic-Type' structure above, but the 'Alternative-Type' looping sequence is applied to the front needle bank. It should be observed that the inclination of the bridging loops slope to the right of a warp line that may be assumed to pass along the centre of the pillar seam for the 'Basic' seam, but they slope to the left for the 'Alternative' seam. The slopes of the bridging loops at the rear of the structures, however, are the same for both types of structures and, if they are viewed through from the front as in the photograph, then the bridging loops slope to the left of a central warp line. This structure also contains the red laid-in warps and therefore it should be compared with the 'Basic-type' structure (Figure 6.11).

6.3 Pillar-Seams Connected by Warp-Lacing

In Section 4.3 a structure was outlined where the pillar-seams were graphically shown as laced together with yarns that progress in the warp direction. As all six warps in each bank have to be manipulated simultaneously, two additional guide bars were made and used.

For making of the pillar-seams two differently coloured rug-wools were selected, green for use with the front needles and yellow for the rear needles. The available front lacing warps were black and the rear warps were white, to ease the tracing of the progress of the yarns within the structure.
FACE VIEW

REVERSE VIEW

FIGURE 6.12
6.3.1 Model of a 'Basic-Type' Structure

Figure 6.13 illustrates a front view of a warp-laced fabric of the 'Basic-Type'. The structure is rather elastic as it consists of loops only, but the low-stretch stability is almost the same in the warp direction as in the weft direction, although the stability depends upon the loop sizes and the friction characteristics of the structuring yarns.

Added warp-wise stability is achieved by a simple warp laying process. One such structure is shown in Figure 6.14, which incorporates straight laid-in warps coloured red.

The weight of this type of fabric is high, because at some intersections the structure may be five yarns deep, yet the 'cover' is not particularly high. However the manufacturing machinery could be relatively simple, consisting of two needle banks and two warp-lacing guide bar banks. Some difficulty was experienced in the manual lacing, because of the lack of adequate guide support and excessive variations of yarn tensions.

6.3.2 Model of an 'Alternative-Type' Structure

For simpler comparison with the 'Basic' structure, the types and colours of the yarns were retained for the 'Alternative-Type' warp-laced structure. The difficulties of making these structures were similar in nature to the making of the 'Basic' structures; only one such fabric is illustrated in Figure 6.15 which also incorporates the red-coloured straight warps. The characteristics of the two types of structure also appear to be similar.

It would be possible additionally to incorporate weft-lays as was shown graphically in Section 4.3. However it was considered to
be impracticable to suggest such complexity to the proposed mechanisms for experimentation purposes, as laying-in wefts on wide working widths is extremely difficult.

6.4 Loops Intermeshed with Adjacent Wales

The largest and the most promising group of potential fabrics appears to be that which is based on the intermeshing of loops with the adjacent wales by the bridging loops of the same looping yarns. The main advantages appear to be lower yarn contents of the structures, and possibly simpler manipulation requirements by the machinery.

6.4.1 Models of the 'Basic-Type' Structure

Illustrated in Figure 6.16 is the 'Basic-Type' structure in which both front and rear needle banks shog one seam pitch to interact with their immediate neighbouring seams on each successive looping cycle. The photograph (Figure 6.16) is a direct face view of the fabric, the green 'yarns' are introduced by the front needle bank and the yellow 'yarns' are introduced by the rear needle bank. The appearance of the structure is similar to a 'tricot' knitted fabric with similar yarn characteristics.

A photograph of another model structure of the 'intermeshed' type is shown in Figure 6.17. In this structure both needle banks are shogged two seam pitches to interact with the next but one seam, the 'shogging' alternate in direction on each successive looping cycle. In addition straight, red-coloured warps are laid-in to increase the warp-wise stability of the structure.
6.4.2 Model of an 'Alternative-Type' Structure

Again, to provide an easier comparison with the 'Basic' structures, the same yarns and the same needle bank shogging sequences are adopted for the examples of the 'Alternative-Type' model structures. Figure 6.18 illustrates an 'Alternative-Type' structure which may be directly compared with the 'Basic-Type' structure illustrated in Figure 6.16 overleaf. The other structure, which was illustrated in Section 6.4.1 (Figure 6.17), is compared here with the two-seam intermeshed structure of the 'Alternative-Type' illustrated in Figure 6.19. Again the rear views of the corresponding photographs are identical, and differences in the loop arrangement may be observed and compared from the visible side in the photographs.
Past experience shows that ideas or hypotheses alone of potentially good products or processes are seldom successfully adopted by industry. However, a practical demonstration, even on a reduced experimental scale, raises the confidence level. Moreover, when a textile product is involved, 'seeing and feeling it' is always highly desirable. Therefore in this work, where the new process and its product was concerned, some hardware experimentation via a powered rig was considered to be essential. For reasons of conciseness only a functional outline of the powered research rig is given below, all details of design procedure having been omitted; supplementary details of bought-out drives etc. are enumerated in Appendix III.

7.1 Basic Concepts

7.1.1 Summary of the Needs

Some probable fabric structures have been diagrammatically outlined in Chapters 4 and 5 and as large-scale models in Chapter 6. Using the physical analogy of the orbital sequence of the yarn manipulation (see Section 3.2) the engineering requirements are enumerated in Table 7.1. For convenience the space is defined in the usual three axis system, where: the x is defined horizontally (transverse to the fabric plane); y is vertical; and z is horizontal along the weft or machine axis.

Three-dimensional movements for two needle bars and auxiliary
<table>
<thead>
<tr>
<th>STRUCTURE</th>
<th>PRIMARY REQUIREMENTS</th>
<th>SECONDARY REQUIREMENTS</th>
<th>AUXILIARY REQUIREMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Seam</td>
<td>2 needle-bars; y) motions; z)</td>
<td>1 or 2 guide bars; 1 guide bar (elastic yarn)</td>
<td>warp feed; chain take-up; looping-zone control.</td>
</tr>
<tr>
<td>Pillar Seams Connected by Weft Lays</td>
<td>2 needle-bars; y) motions; z)</td>
<td>1 or 2 warp-lay bars; x)</td>
<td>warp feed; looping-zone control; fabric take-up.</td>
</tr>
<tr>
<td>Pillar Seams Connected by Warp Lacing</td>
<td>2 needle-bars; y) motions; z)</td>
<td>1 or 2 warp-lay bars; x)</td>
<td>warp feed; looping-zone control; fabric take-up.</td>
</tr>
<tr>
<td>Loops inter-meshed with adjacent wales</td>
<td>2 needle bars; y) motions; z)</td>
<td>1 or 2 warp-lay bars; x)</td>
<td>warp feed; looping-zone control; fabric take-up.</td>
</tr>
</tbody>
</table>
functions is the minimum need for the generation of the separate seams. Also, in the initial rig design, the author decided to incorporate the z-direction shogging facility for both needle bars; means for operating the pillar seam interlacing warps; means for laying-in warps; additional driving facilities (in x and y directions) for looping-zone control; means for warp feed and fabric take-up. However, the weft-laying systems, required by one group of structures, were initially set aside.

7.1.2 Conceptual Outline

The author's primary concern in the early part of this design, was to provide the maximum functional versatility within the one unit, i.e. to fulfil all projected experimentation requirements. An arbitrary 150 mm were chosen as the maximum working width. Variable running speeds were arranged to reach at least 1200 courses per minute, i.e. the current maximum speed of the fastest tricot machines, (see Section 2.2). The orbital motions were to be generated by crank-driven linkages, wherever possible, or cam-driven linkages otherwise. Several concepts were similar to those used on the author's previous rig for manufacturing locked-stitch pile fabrics, e.g. all-round access and observation visibility, the use of operational linkages (in such design the author has considerable experience), controlled warp feed etc. Moreover, the design was to be a compromise of convenience and expediency within the context of the development here described.
7.2 General Structure

Figure 7.1 is a photograph of the whole research rig shown at an advanced stage of development. Structurally it consists of a stand, subframe, superstructure and a separate warp package creel.

7.2.1 Stand

The approximate overall dimensions of the rig were determinable from the fixing of the working width (see Section 7.1.2 above) and the adoption of the 'Locstitch' rig layout. This led to a relatively small and low unit hence for convenience in access to the working zone it was decided to elevate it via a stand.

The stand is a 'Speedframe' (1 inch square tubing) structure, 571 mm long, 914 mm deep and 648 mm high and additionally stiffened in all top corners by angle-brackets. The weight of the subframe and superstructure (see the following Sections 7.2.2 and 7.2.3) is supported by four upright corner members 1, Figure 7.1, horizontal members 2, 3 etc. form a platform for the mounting of the subframe and other attachments. The stand is hollow and it houses the electric motor and the speed variator (see Section 7.3.1), both being mounted on a separate cradle. The drives and the stand are free-standing on feet that raise the horizontal members 14, Figure 7.1, about 75 mm above the floor level; this facilitates the accommodation of the yarn-tubes that pass beneath the stand to the front of the rig. All sides and the top are covered with block-board guards, some including ventilating louvres to permit adequate cooling of the drives.
7.2.2 Subframe

Figure 7.2 shows the subframe in a pictorial view. For the support of all the mechanisms the welded structure was deliberately overdesigned, using a hot-rolled steel channel of 3 x 2 inch section, in order to absorb some of the incidental disturbing forces that usually arise in this type of work. It was anticipated that self-aligning bearing units would be used for the support of the driving and lay shafts thus obviating most of the precise, otherwise necessary, machining. For the mounting of auxiliary mechanisms additional plates and brackets were attached to this rigid subframe, which itself was fastened with bolts to the platform members of the stand.

7.2.3 Superstructure

Clear perspex plates (\(\frac{3}{4}\) inch thick), 4 and 5 in Figure 7.1, are the main structural members of the superstructure. The plates are attached to the subframe via angular brackets 6 and 7, in Figure 7.2; screwed stays 8, 9, 10, etc. in Figure 7.1, provide lateral stability (in this plane the plates themselves offer limited rigidity). Clear perspex was used extensively in preference to other structural materials, because of its transparency and adequate strength. The bearing units such as 15, 16 in Figure 7.1, and slideways 17 are directly mounted on the perspex end plates, yet the stitching zone may be observed from all sides of the rig; (some photographs for this work have even been taken through the plates).

Additional perspex plates 18 and 19, in Figure 7.1, extend on both sides of the rig along the subframe to support the yarn feed
ROLLED STEEL CHANNEL 3×2 in.

ALL DIMENSIONS IN MM

FIGURE 7.2
and tensioners. At the control end of the rig, the drives are mounted on fabricated mild steel brackets such as 20 and 21 in Figure 7.1, which are attached to the side of the channel section subframe.

7.2.4 Creel

Figure 7.3 shows part of the 320-end package creel in its general attitude to the powered test rig. For convenience a free-standing 'Dexion' structure has been assembled to support the small yarn packages and the necessary yarn guides. It consists of four upright angles, 1, 2, etc., and four tiers of horizontal trays 3, 4 and 5 are shown in Figure 7.3, these being topped with block-board 6, 7 and 8, for resting the supply packages on, and for attaching the many guides to that are necessary to facilitate adequate yarn control.

7.3 Drives

7.3.1 Primary Drive

Figure 7.4a shows the subframe (guard removed) exposing the prime mover 1; triple 'A'-section 'V'-belt drive 2 and the input-end of the Carter hydrostatic speed variator 3, (see Appendix III for more details of the transmission equipment). An electro-magnetic clutch couples the output of the speed variator to the driving shaft which is emerging at 11, in Figure 7.1; this is transmitted further via a toothed belt drive 12 to a layshaft 13, in Figure 7.4; a direct ratio toothed belt and pulleys 14 drive the front camshaft 15; the layshaft 13 also drives the rear camshaft 16 in the opposite direction via 1:1 ratio gears 17 and 18.
FIGURE 7.4
For convenience the electric motor 1 and the Carter speed variator 3 were chosen with a power capacity substantially in excess of the projected requirements. All bearings such as 19 in Figure 7.4, are unit type, either plummer block or flange mounted units, which are readily available, as are 'V'-belts, toothed belts and most gear drives.

7.3.2 Secondary Drives

It has been outlined above (Section 7.1) that three-dimensional movements of the needles and other yarn manipulating elements would be required. These needs are governed by severe kinematic and dynamic limits for very precise interaction as only few functions may be considered independently. Although at this stage of the rig design the precise requirements of each function were not fully known, it was, however, certain that motions in the three mutually perpendicular directions would be required. It is feasible to generate such three dimensional motions from a single rotating input such as a rotating shaft, but in the author's opinion, for the convenience or more rapid development, it was decided to provide a transversely rotating input source for generation of the z motions.

Figure 7.5 shows the 1:1 transverse drive to the mechanisms for z-motions; helical gears 1 and 2 drive the cross-shaft 3 via an adjustable coupling 4 (for eventual timing adjustments) and universal joints 5 (to facilitate alignment). In the z-motion mechanism itself, this drive is split in two contra-rotating shafts via gears 6 and 7.

For convenience the selecting shog cam-shaft, 8 in Figure
7.5, is driven from the layshaft, 20 in Figure 7.4, via 1:4 ratio helical gears 21 and 22, shaft 23 and direct ratio toothed-belt drive 24 (only the top pulley shown in Figure 7.4). Shaft 23 in Figure 7.4, also drives the fabric take-up roller, 9 in Figure 7.5, via the chain drive 25 in Figure 7.4, 'Haynau Mini-drive' speed variator 26, and worm-drive 10 and 11, in Figure 7.5. The layshaft, 20 in Figure 7.4, also provides the power take-off for the yarn feed (see Section 7.5).

7.4 Needle Motions

7.4.1 Primary and Secondary Motion

The orbit of the needles formed the datum around which all the other elements would have to comply and this was based on the orbit employed on the 'Locstitch' process, since it has been shown in Sections 3.2 and 6.1 that two-yarn chain seams could be made in such a manner, but without the presence of base fabric.

However, the main design criteria for the needle orbit were based on the physical size, shape and dynamic properties of the needle drive linkages. Some of the design requirements were:

i) the needle drive mechanism should be duplicated on both sides of the machine (without any links passing through the fabric plane);

ii) the needle drive should be a pure linkage to obviate the use of expensive cams and their associated mechanical problems;

iii) the linkage system should not interfere with access to or sighting of the knitting zone; and
iv) the linkage system should be sound dynamically.

To meet these physical constraints, the mechanism shown schematically in Figure 7.6 was designed to produce an elliptical orbit. By duplicating this mechanism on the other side of the machine (at 180° phase difference) and adjusting the drive shaft centres, i.e. $2(P+Q)$, to a dimension of 280.2 mm., an acceptable interaction of the orbits was achieved. For the convenience of future work, the linkage was mathematically solved to give Cartesian coordinate positions of the needle point relative to a predetermined datum point on the central plane of the rig. Figures 7.7 and 7.8 are graphs of the needle point loci, in the $x$ and $y$ directions respectively. The $x$ direction will be referred to as the direction of the primary motion and the $y$ direction as the secondary motion of the needles. The combination of the two graphs gives the orbits of the twin needle system shown in Figure 7.9 with the two needle points at an arbitrary station 3. The successively numbered stations are at equal time intervals from each other. This linkage system gives a slight change in the angular position of the needle flank relative to $W_1$ in Figure 7.6, the angle $Z$ direction, and this angular change is given in Figure 7.10, which is caused by the crank-conrod ratio $15$. After designing the individual components of the linkage, it was estimated that the speed of rotation of the drive shaft could be up to 700 r.p.m. without the need for balancing.

7.4.2 Needle Shogging Motion

The needle shogging motion occurring in the $z$ direction was to be driven by a cam and so the displacement curve could be immediately decided upon. The shog to pick up the yarn should
L. H. MECHANISM

ALL DIMENSIONS IN MM

A=2.39  P=177.8  'x'&'y'=CO-ORDINATES OF NEEDLE
B=173.2  Q=102.4  POINT
C=50.8  R=7.9  'sh x'&'sh y'=CO-ORDINATES OF POINT 'V'
D=63.5  S=77.0  (AT WHICH THE NEEDLE
E=62.1  T=44.6  BAR IS SHOGGED)
F=234.3  U=43.8
G=300.8  θ=90°
H=94.8  W=DEGREES

FIGURE 7.6
ideally occur at the last possible moment when the needles are in a collision plane. However, because the needles were required to shog 2 mm. to pick up the loop, it was decided to minimise the time required by making both needle banks move in opposing directions at half the displacement needed such that the relative motion between each bank was fast but, at the same time, the acceleration characteristic was dynamically sound and one needle bank would tend dynamically to balance the motion of the other. The needle shogging motions are shown in Figure 7.11.

7.5 Yarn Feed

Figure 7.3 shows the nature and path of the yarn supply to the research rig. The feed is basically a negative-type let-off motion but is assisted by a self-serving friction drive, 9 in Figure 7.3. The yarns are drawn-off vertically over the ends of packages 10, through spiral eyelets 11 which are attached to the board 8, via guides 12, 13 and 14, into the small-bore PVC tubings 15, to pass underneath platform 16 and leave the tubings at collector board 17; guides 18 and 19 deflect the yarns around the roller 9 before passing them through a collective-type disc-brake 20; then guides 21 and 22 take the yarns into the knitting zone on the rear-side of the rig.

The roller 9 is driven continuously at a surface speed which slightly exceeds the maximum demand rate of the yarns; thus when friction increases upstream from this roller, this serves to increase the pressure between the yarn and the high-friction (rubber) roller surface; therefore, the yarn tension in the stitching zone will probably remain substantially constant.
FIGURE 7.11

R.H. NEEDLE BANK

L.H. NEEDLE BANK

CRANK ANGLE (W)

DEGREES

45° 90° 135° 180° 225° 270° 315° 360° 45°
Similarly, from the lower board, 6 in Figure 7.3, the yarns are taken on a similar path along tubings 15, to pass underneath platform 16, but in this case also underneath the sub-frame 23, to emerge through a collector board, 13 in Figure 7.1; thenceforth they move over a similar servo-roller and friction discs system to the front of the stitching zone.

Creeling of this type, and use of tubing (such as 15 in Figure 7.3) for yarn guiding over tortuous paths, is common practice in tufting processes, where the number of warp-ends is also not excessive.

7.6 Fabric Take-up

Figure 7.12 shows diagrammatically the layout of the fabric take-up. The variable speed drive to the take-up roller 1 was outlined in Section 7.3.2. Rollers 2 and 3 are also driven via spur-gears from roller 1, but the fabric is not nipped between the adjacent rollers; thus to effect a fabric take-up some tension T must be applied to the fabric. For this purpose, a secondary tensioner was designed and this is also shown in Figure 7.12. This secondary tensioner unit pivots at 4 with a moment applied by an adjustable dead-weight 5; a continuously rotating disc 6 (which is mounted on the connecting drive shaft of the yarn-feed) drives the rim of disc 7 by friction, and, via a very light chain 8, it rotates the tension roller 9. A spring loaded roller 10 nips the fabric onto the surface of roller 9, thus any rotation of roller 9 serves to increase the value of tension T. The speed ratio between discs 6 and 7 is variable but, in normal running, the sur-
Face speed of the roller 9 is at least as fast as that of the roller 1. It should be noted that the fabric take-up rate is determined by the surface speed of the roller 1.
8.1 Looping by the 'Locstitch' Principle

Section 3.4 outlined the envisaged problems of achieving the practical loop formation by the proposed twin-needle system and this chapter will describe preliminary experiments to investigate these.

In conventional knitting processes, the new loop is pulled through the old loop, which is embracing the shank of the element; therefore, provided that the yarn has been gathered by the hook and the hook is closed, a new loop will be made. By contrast, on the proposed twin-needle system the new loop is to be pushed through a loop which is made-up of the complementary needle on one side and the suspended pick-up yarn on the other side. This action is similar in principle to the operation of the 'Locstitch' system. The author\(^1\) and Vine\(^10\) (Chapter 9) indicated that the reliability of the 'Locstitch' process was dependent upon the accuracy of needle closure, i.e. the precision by which the point of one needle passes by the flank of its complementary needle. It was also concluded that the needle deflected because of the constraining effect of the base fabric and therefore the accuracy of closure could not be maintained. However, it is reasonable to expect that if no base fabric were present to induce needle deflections, then the accuracy of needle closure would be considerably improved.

To make the first structure at speed on the new powered rig (see Chapter 7) the bars were fitted with short banks of 'Locstitch' needles and their operating mode set to simulate the 'Locstitch'
needle orbit (see Section 3.1 and Figure 3.1). Using 100 tex Courtelle spun yarns (inherited from previous researches\textsuperscript{1,10}) a multiplicity of separate 'Basic' type chain seams were produced. However, the reliability of looping was totally unacceptable, and in evidence the photograph (see Figure 8.1) shows several faulty chains alongside a correctly looped chain marked X. Such unreliability was caused not by inaccuracy of needle closure but by the inadequate positioning of the yarn that the complementary needle had to pick-up i.e. without the existence of the base fabric (as present in the 'Locstitch' process) the yarn extending from the needle eye to the finished seam was not positioned at a sufficiently accurate point in space for satisfactory pick-up by the entering needle.

8.2 Introduction of the 'Pick-up Shog'

The above experiment served a very useful purpose by providing an actual size spatial model of the knitting zone, shown in Figure 8.2(a, b, c and d). Observations of the yarn positions at various stages in the needle cycle supported the assumptions made in Section 3.4, and illustrated in Figure 3.13, namely that reliability of the novel knitting process would be most likely achieved by the precise formation of the pick-up triangle. This triangle, being a relatively large opening, ought to ensure accurate penetration by the approaching needle point.

The major portion of the development described in this chapter is concerned with the formation of this pick-up triangle and for convenience of subsequent reference it is re-illustrated in Figure 8.3.
FIGURE 8.1
FIGURE 8.2
FIGURE 8.3

PICK-UP YARN
PICK-UP TRIANGLE
LOOP CORNER
LOOP YARN
BASE CORNER

EYE CORNER

TAKE-UP TENSION
Instead of the needles forming an accurate closure with their complementary set, the motion of the needle bar was modified to incorporate a side-stepping (shogging) motion. By such means the needles made exactly the same planar orbit but, during the period when they were not interacting, the trajectory of the needles was arranged such that they would otherwise collide with each other. The needles thus approached their complementary set on a collision course up to that point in the cycle where the suspended yarn could be picked-up; at this stage, the shogging motion of the needle banks produced the pick-up action and thus allowed the needles to interact between the space of the adjacent complementary needles. This three-dimensional motion of the needles considerably improved the reliability of the process and the need for a needle point accurately to pass the flank of its complementary needle was obviated.

8.3 Orientation of the Needle-Eye

The type of needle 'side-stepping' (described in Section 8.2 above) offered the possibility of picking up the yarn on either flank of the complementary needle, provided that the attitude of the needle eye was turned through 90°. A set of such needles (conveniently termed 'warp-wise' eyed needles) were manufactured and indeed the yarns could be successfully picked up by shogging these needles, to 'side-step' their complementary warp-wise eyed needles. Dynamically this system would make optimum use of the needle shogging motion, but it has two major disadvantages: (i) reducing the fineness limit of the machine gauge, and (ii) increasing the bending strain on the yarns during the looping cycle.
The limitation to machine gauge (needles per unit of needle bed length) is dependent on the section size of the needle in the transverse plane and, with the needle eye in this plane, the minimum practical needle pitch is 2.97 mm (0.117 in). Such a gauge (8.5 needles per inch) does not appear at first sight to be too coarse but when the relative size of the needle eye is considered, and thus the maximum count of the yarn that may be used (approximately 6 cotton count, 10 metric count, spun yarns, and 740 denier, 82 tex, filament)\(^{14}\), it is the author's opinion that the density of the fabric produced would be poor.

Only a small reduction of the pitch would result if the needles were relieved behind the eyes as shown in Figure 8.4; also with such needles the eye portions would need to interact with the relieved portions of their complementary needles, and vice versa during the other half of the operating cycle, and this could be an added design constraint.

To investigate the distortion of the yarns during the manipulating cycles (as was suggested above) large wooden models (10x scale) were again used. Figures 8.5 and 8.6 are cross-sectional views of the two types of needle along the fabric plane when looking towards the rear of the arrangement. The critical region is the eye of the needle as the yarn is being pulled through it under tension, and it is clearly seen that, in the case of the warp-wise eyed needles (Figure 8.5b) the wrap-angle is double in size relatively to the corresponding wrap-angle for the weft-wise eyed needles (Figure 8.6b).

For the two reasons outlined above (i.e. low fabric density and high yarn distortion) it was decided not to pursue the process
WARP-WISE EYE

(a)

FIGURE 8.5

WEFT-WISE EYE

(a)

FIGURE 8.6
of using the warp-wise eyed needles but to revert to banks of needles with the eyes running weft-wise. In fact, all the existing eyed-needle processes, e.g. 'Locstitch', tufting, 'Kraftmatic' etc., have the eyes running weft-wise to make efficient use of the needle section/strength ratio.

8.4 The General Arrangement of the Elements

The needles so far used were identical on both sides of the rig; furthermore, their motions were also identical but with a phase difference of 180°. Similar needles however may be related differently to their complementary set of needles if the shogging motions are changed accordingly. Such changes of the shogging motion are in the nature of sequential movements and of displacement magnitudes.

Figure 8.7 shows an elevation and plan view of symmetrically arranged offset-point needles in which the pick-up yarn is suspended from the curved flank of both sets of needles. A simplified shogging displacement-time diagram (Figure 8.8) illustrates the shogging requirements of these two needles in order to produce a single 'Basic' seam, and Figure 8.9 shows the same requirements for a one seam-pitch intermeshing fabric construction.

A different arrangement of similar needles is shown in Figure 8.10, in which the pick-up yarn is suspended from the same side of both needles. Figures 8.11 and 8.12 illustrate the shogging requirements for the manufacture of a single 'Alternative' seam and one seam-pitch intermeshing fabric structure respectively.

It should be observed, from the above diagrams, that the 'Basic'
Figure 8.7

Figure 8.8

Figure 8.9
FIGURE 8.10

FIGURE 8.11

FIGURE 8.12
displacement is 1.5 times the 'Alternative' displacement for single seam manufacture. The displacement for the seam inter-meshing fabric structure is of the same magnitude for both arrangements, but in some parts of the 'Basic' cycle the shogging velocity needs to be double that for the corresponding 'Alternative' cycle.

The shapes of the 'Alternative' type needles are the same as for the 'Locstitch' needles (except for their mounting attitudes) and these are readily available from industrial sources.

Consequently, on the dual grounds of higher manipulating efficiency and of general expediency, the 'Alternative' type seam arrangement was adapted for the actual-size experimentation and this, together with the three-dimensional orbit, described in Section 8.2, again improved the reliability of loop pick-up.

8.5 Addition of Presser-Bar

It has been shown that the correct formation of the knitted seam is dependent upon the formation of a triangular configuration created by the needle, the suspended yarn to be picked up and the loop of yarn previously picked up. The position of only one corner of this triangle can be spatially guaranteed, i.e. the point where the yarn extends from the needle eye, denoted as 'eye corner' in Figure 8.3. The other two corners of the triangle depend upon the finished seam take-down tension which assists the pick-up loop to slide down the shank of the needle to form the 'loop corner' and which also extends the length of this loop to form the 'base corner' of the triangle.
By experimentation it was found that process reliability was
greater with higher seam take-down tensions. However, a high ten-
sion tended to create long stitches and the need to maintain the
tension meant that back-robbing incurred breaking strains in the
yarn. Therefore, it was decided to introduce another element to
assist precise formation of the pick-up triangle without the need
for high take-down tensions.

Extra linkages were added to the rig to provide motion to a
presser bar. The function of this bar was to push the loops off
the outgoing needle and to push the pick-up loops to an accurate
predetermined position along the shank of the pick up needle.
Having achieved this, the seam take-down tension was considerably
reduced, but was still higher than that desired. Figure 8.13
shows four stages in the needle cycle, where the pick-up triangle
can be clearly seen in relation to the needles and the presser bar.
Under these conditions the reliability of production of a single
seam was extremely good.

8.6 Basic Defect of the Process Reliability

The reliability so far achieved was in fact found to be largely
dependent upon the consistency of the yarn used, because, under
steady state conditions, the formation of the pick-up triangle and
accuracy of needle movement was satisfactory. In practice, the yarn
consistency cannot be guaranteed and slubs and knots in the yarn
must be tolerated. It may be acceptable with some existing fabric
manufacturing processes that the occasional knot or slub creates a
dropped stitch without affecting continuity of manufacture, but when
this occurred with the system so far developed, a complete breakdown
On machines that manipulate yarns into looped structures with fixed-stroke elements, the final loop sizes are usually controlled by a back-robbing technique. By this technique, as the geometry of the fixed-stroke element demands a constant length of yarn per operating cycle, therefore any reduction in the length of the supply yarn must cause a corresponding reduction (or back-robbing) of the size of the previously formed loop.
PRESSER BARS - X & Y

FIGURE 8.13
of the process occurred. Although the formation of the pick-up triangle is accurate under steady-state conditions, it is dependent upon the correct formation of the previous stitch which guarantees the existence of the base corner of the triangle. A dropped stitch fails to form the base corner and all subsequent stitches fail. To correct the fault the process must be stopped and the offending loops must be manually placed in their correct positions until a sufficiently corrected seam length is produced, thereby returning to steady-state conditions. This inability of the process to recuperate after dropping only one stitch was totally unacceptable, and therefore, it was concluded that the presser bar offered only a partial solution to the problem; nevertheless it served to demonstrate precisely what function an additional knitting element ought to perform.

8.7 Introduction of the 'Grabber'

To perform the above suggested functions a new element was needed and for convenient future reference it will be termed the 'grabber'. Firstly, this grabber element must push the picked-up yarn loops down the shank of the needle (as the presser bar did), and secondly, it must position the base corner of the triangle at a known point in space independently of the formation of the previous stitches. In so doing, the seam take-off tension may be theoretically zero because all corners of the pick-up triangle will be formed by the mechanical components rather than by yarn and seam tensions.

To perform the function of the superseded presser bar the nose of each grabber element had to lie across the shank of the needle.
In order to achieve this the needles were cranked (in their non-working shank area) to allow the grabber nose to come up through the spaces between the adjacent needles. Thus as the grabber moved over the working length of the needle its nose lay transversely to the seam and pushed the pick-up loops down the shank of the needle on the complementary bank. Figure 8.14 illustrates this relationship in two orthographic views. Having performed this function, the grabber moved to a point in space to hold the next yarn to be picked up in a predetermined position irrespective of the correct or incorrect formation of the previous stitch.

The system has now evolved into a concept of manipulating knitting elements which appears to be a practical and commercial proposition. Therefore, before considering the procedure for producing structures by seam interaction and analysing the yarn tensions and feed requirements etc., the development of the mechanical movements, the components, and the manipulating elements, will be described in more detail.
END ELEVATION

PLAN

FIGURE 8.14
CHAPTER 9

DEVELOPMENT OF THE NOVEL PROCESS
VIA THE POWERED RESEARCH RIG

The fabric plane and the planar orbit of the needles (outlined in Section 7.2) were chosen as the reference datums for development of all the auxiliary elements and their functions. Although the experimentation was conducted on a narrow working width of the rig, the author was fully appreciative of the need to ensure suitability for scaling-up in all aspects of this work.

9.1 Grabber Motion

9.1.1 Primary and Secondary Motion

The determination of the grabber motion presented considerable problems. The prime objective of the grabber is to manipulate the yarn into predeterminate positions (see Section 8.7). It interacts between the gaps in adjacent needles and the needle motion is in three dimensions. Thus the grabber motion could not be considered in isolation. The technique devised was to draw, to a high degree of accuracy, sixteen needle positions at equal time intervals over one needle orbit to a 10-times scale; then the required position of the yarn, such that the needles could not fail to pick it up, was added to these drawings. A template of a proposed grabber shape was then superimposed on each of the sixteen needle drawings and positioned so as to hold the yarn as and where it would be required. Two typical positions to a reduced scale are shown in Figure 9.1. These sixteen grabber positions were noted relative to the needle positions and plotted. Naturally the initial plot was somewhat ad hoc and conventional curve-fitting techniques could not be used to
provide a smooth curve through the sixteen points. It will be appreciated that the displacement of the grabber must be dynamically sound and so the graphically determined displacements were split into x and y coordinate positions. Using sine curves the computer was used to fit a compound motion through the precision points in both the x and y directions independently. Thus the two displacement curves shown in Figures 9.2 and 9.3 were derived and checked by finally drawing the derived grabber positions accurately onto the needle station drawings. The task remained to design the cam linkage system to produce these motions. The criteria for the design was the same as that for the needle motions and it resulted in a system shown schematically in Figure 9.4. It will be appreciated that the cam that predominates the motion in the x direction will affect the grabber position in the y direction and vice versa. Therefore, one cam could not be designed in isolation from the other. Again the computer was used to design the machining polar coordinates of the interdependent cam sets.

9.1.2 Grabber Shogging Motion

A similar graphical technique was used to determine the motion of the grabber in the z direction. However, extra precision was required where the grabber moved around the crank in the needle, especially as the needle itself was moving in three dimensions at this stage of the cycle. These extra time-coordinated needle drawings were made at 5 degree intervals to ensure that the computed sine curve motion was satisfactory. The resultant grabber z displacement curve is shown in Figure 9.5.
L.H. MECHANISM

ALL DIMENSIONS IN MM

A=6.0  M=6.8
B=3.4  N=5.2
C=10.7  P=17.8
D=8.6  Q=10.2
H=9.5  V=6.8
J=17.3  W=1.9
K=6.7  $\theta_1=12.13^\circ$
L=17.3  $\theta_2=167.96^\circ$

x & y=GRABBER DISPLACEMENTS
(SEE FIGURES 9.2&9.3)
sh x&sh y=CO-ORDINATES AT WHICH
GRABBER BAR SHOGS

FIGURE 9.4
9.2 Design of the Shogging Mechanisms

9.2.1 Needle and Grabber Shogging Mechanisms

The unit for providing all the shogging motions to both the needle and grabbar bars was designed as a single module. All motions were derived from cams but to achieve the motions shown in Figures 7.6 and 9.5 for the $x$ direction, drive rods had to extend from the modules to the bars of the elements. A schematic design of the shogging module is shown in Figure 9.6. The cam profiles used had to compensate for the two-dimensional motion of the drive rod ends (in the $x$ and $y$ plane) as well as provide the required $z$ directional motion. Therefore the mechanism was mathematically analysed and the computer used to give cam machining polar coordinate dimensions.

9.2.2 Seam Interaction Shogging

Initially the arrangement so far described was used to assess the reliability for producing single seams of interlooped yarn. However, the shogging module was provided with a segmented cam so that, at a later stage, seam interactions could be tested thereby producing fabric. The seam interaction cam acted on the needle bar and, since the needle bar already had a shogging movement to pick up the loops, the mechanism was arranged as a 'series-cam-set', i.e. the total shog of the needle bar was the sum of the pick-up shog and the interaction shog (see Section 7.4), the latter being readily changeable to facilitate different fabric constructions. As previously stated, the latter tests were made by making single 'Alternative' seams of interlooped yarn.
ALL DIMENSIONS IN MM

A = 21.2
B = 32.9
C = 4.8
D = 13.1
E = 9.0
F = 3.6

G = 9.0
H = 6.5
J = 6.2
K = 1.8
L = 9.8

'z' = SHOG DISPLACEMENT
'sh x' & 'sh y' = CO-ORDINATES AT WHICH GRABBER AND NEEDLE BARS SHOG

FIGURE 9.6
9.3 **Grabber Performance**

The grabber performed as expected and additionally to pushing loops down the shank of the needles, it also controlled the base corner of the pick up triangle irrespective of whether a previous stitch had been formed correctly. However, there was a further unforeseen advantage of the grabber which related to the initial threading up of the needles. Previously each new yarn to be threaded had to be taken through the needle eye and round the take down rollers before knitting could commence, and this was an awkward procedure. With the grabbers in operation, the new yarns could be threaded through the needle eye and the grabber itself would automatically carry the loose end of yarn into the knitting zone such that production could commence immediately. The design of the grabber was such that any yarn placed in its path as it moved into the knitting zone was carried into the zone and laced into the seams. Therefore, fabric could be produced without seam interaction by tying together the individual seams with weft lay yarns. An example of this is shown in Figure 9.7 which corresponds to the 'Alternative' large scale model in Section 6.2.2. The fabrics produced in this way were fairly interesting and could have various applications, but it was realised that the most versatile systems for fabric manufacture would necessitate seam interaction.

9.4 ** Seam-Intermeshed 'Alternative' Fabric**

9.4.1 **Seam Interaction**

With the action of the grabbers producing a high degree of reliability, it was possible to study the effects of seam interaction. By such means it is possible to produce a fabric without the need for
FIGURE 9.7
extra weft-laid yarns. The seam interaction cams were cut to give a one pitch shog per needle per cycle, as shown in Figure 9.8, and a single seam intermeshed 'Alternative' fabric was produced with an indication of good reliability for the eventual machinery to be based on this technique.

9.4.2 Selvedges

Initially the selvedges produced on a narrow-width of fabric were poor. This was because extra needles were present which were not carrying yarn at the edges, i.e. the width of the fabric produced was not the total capacity of the rig. A very satisfactory selvedge was produced by using exactly the same number of yarns as there were needles in the bank and by incorporating a spring take-up on the four yarns comprising the selvedges. The spring compensators (see Figure 9.9) take-up the unused yarn when the shogging has taken the needle outside its opposite complementary needle.

9.5 Yarn Feed

The yarn feed system was designed somewhat empirically, being based on that designed by the author for the 'Locstitch' rig with a friction roll driving the yarn from the creel when the demand tension increased. The tension increased when the needles moved forward demanding yarn from the supply, but the rig was equipped with a reciprocating bar that could be phased to induce tension at any stage in the needle cycle. After considerable experimentation with the phased reciprocating bar it was found to be superfluous. The most satisfactory stage in the needle cycle for increased tension (and hence yarn feed) was in fact when yarn was demanded by the needles. Figure 9.10
ONE REVOLUTION OF 'SHOG' CAM SHAFT

ONE NEEDLE CYCLE

ONE 'SHOG' CAM SEGMENT

FIGURE 9.8
YARN TO SELVEDGE NEEDLE

SPRING COMPENSATOR

FIXED GUIDES

YARN FROM SUPPLY

FIGURE 9.9

FIGURE 9.10
shows the tension recordings of a yarn and although the tension is not constant it has been maintained at a maximum peak of 0.2 N approximately. This is considerably lower than conventional warp knitting tensions (approximately 0.5-0.7N), but because of the cyclic characteristics, it is too early to say whether an improvement has been achieved. The tension curve exhibits two peaks per needle cycle, the larger occurring as the needles move forward and the smaller peak when the grabbers are moving down to hold the base corner. The primary function of the yarn tension system was to increase the definition and reliability of formation of the pick-up triangle. By retaining relatively high tension as the needles move forward, the pick-up yarn triangle, from the eye corner to the base corner, was accurately formed. However, the needles carrying the pick-up triangles start to retract slightly before pick-up is complete and this causes a relaxation of yarn tension. Therefore, experiments were conducted to maintain yarn tension a little longer until pick-up was completed, but these produced no satisfactory solution with the mechanisms provided on the rig; hence, a considerable redesign of the yarn feed would be necessary. However, accepting the fact that the existing yarn/tension system was by no means optimised, the initial process reliability and good fabric density indicated that the proposed fabric manufacturing process was promising.

9.6 Examination of Reliability Problem

9.6.1 Yarns Used

Most textile machinery designers would concede that no one process could accept all the different types of yarn that are commercially available. The compromise is to develop processes that will
accept a very wide range of yarns and this must obviously be a criteria for the new fabric manufacturing process. The needle used is in principle a tufting needle, its eye being of a standard size for a 5/64 inch (2mm) gauge machine. The needle manufacturers, Singer U.K. Limited, state that for this size eyed-needle the minimum yarn count should be 6's cc. Such a yarn, with the rig's needle pitch of 2.2mm, and with seam interaction, produces a fabric of reasonable density (see Figure 9.11). However, the use of 6's cc Courtelle and similar spun-fibre singles yarns produced an undesirable phenomena when yarns having the same twist direction were used on both sides of the machine in that their natural twist liveliness caused snarling in up to 4 adjacent yarns during the low tension part of the cycle; the twisting together of these yarns was so intense that they could not be corrected by increasing the yarn tension. If this situation is allowed to continue, a variety of complex tension conditions occurs in the knitting zone where the snarled yarns are pulled by the needle and grabber elements. This occurrence is not in itself surprising, but what is interesting to note is that it only happens on one side of the machine. To investigate this phenomena further the offending side of the machine was threaded with a yarn of opposite twist direction (i.e. S twist one side, Z twist the other side) and the problem was solved. The provision of yarn twist balancing is well-known in certain sections of the textile industry, e.g. yarn doubling, weaving, etc. but for this type of fabric production it is sufficient to note that when using twist-lively yarns the total process needs to be mirror imaged; as previously stated, the knitting elements on each side of the machine are mirrored and this has consequently created a similar need to balance the yarn twist characteristics (see Figure 9.12). However, when
FIGURE 9.11
2-ply yarns were used; the above phenomena did not occur with either S or Z twisted yarns. This was probably due to the twist balancing caused by each yarn in the ply having fibres twisted in the opposite directions to the ply twist to provide a yarn with a neutral or low twist liveliness which could be run satisfactorily on either side of the machine. The most reliable knitting was produced using a 2-ply acrylic fibre 'Orlon' yarn of approximately 2/26 cc with few or no stray fibres protruding from the yarn, i.e. each yarn in the ply had the high twist factor whilst the ply twist was fairly low. However, the process should function reliably with a variety of yarns and it seems reasonable to assume that, having achieved success with standard types of low quality yarn, then success with higher quality yarns ought to be achievable also.

For further experimentation it was decided to use a 2/26 cc loosely spun yarn of average quality comprising 75 mm staple length acrylic fibres. With this yarn a seam-interacted fabric was produced on the research rig at speeds up to 600 rev/min (1200 courses/minute). Faults in the fabric due to dropped stitches (i.e. failure to pick up the loop) resulted in a hole in the fabric in localised spots, but the total process did not break down. Because the type of yarn to be used for the research was now fixed, further investigation of these failures was required.

9.6.2 Dispersion of Failures

The speed of fabric production was very impressive and long lengths of 100mm wide fabric could be quickly run off. Inspection of the fabric revealed that in some cases, for a particular warp seam, a dropped stitch occurred fairly regularly (say every 70 or 100mm) but there were other failures occurring at random (see Figure 9.13
FIGURE 9.13

DROPPED STITCHES
where the failures in a typical section of fabric have been highlighted). However, it was to be noted that in many seams (approximately 50%) no failure occurred at all. Failures occurring regularly in a particular seam indicated the inaccuracies in the interactions of the knitting elements within that seam; indeed a repositioning of the needle banks and 'pliering' of the needles made a significant improvement. The randomly occurring failures were more difficult to analyse and required the postulation of hypotheses which could be subject to further experimentation as described in the remainder of this chapter.

9.6.3 Fluctuations in Yarn Tension

As previously described the yarn tension per cycle varied; recordings show that the cycle repeats with reasonable consistency as normal knitting proceeds. No equipments exists for measuring each yarn tension in a warp simultaneously and, therefore, the tension of selected individual yarns were measured, the rig being run until a failure occurred in the seams being monitored. When a dropped stitch occurred there was indeed a change in the yarn tension characteristic, but it was not possible to establish whether this was a cause or an effect of the failure.

9.6.4 Formation Consistency of Pick-up Triangle

While previous observations show that the formation of the pick-up triangle was accurate, it has not yet been established whether this accuracy was maintained during continuous duty. The three sides of the triangle are formed by the needle shank, a loop of yarn over that shank, and the yarn to be picked up extending from the needle
eye. The eye-corner of the triangle can be guaranteed within a deflection tolerance as it is dependent upon a solid mechanical component. The loop corner of the triangle is determined by the pushing action of the grabbers, but its position may be different due to varying friction characteristics between the yarn loop and the needle shank. Also, these frictional characteristics are a function of yarn tension and quality, both of which will vary slightly at the formation of every stitch. However close observation of the picking-up procedure over an extensive number of stitches (even those stitches that are dropped), revealed that the position of the loop corner of the triangle was not critical to the process reliability. The only possibility of the loop corner position causing a failure would be if the loop was insufficiently far down the needle such that the picking-up needle caught it. This occurrence has never been observed under normally set conditions. Therefore, if the failures are caused by the inconsistency of the pick-up triangle formation, the base corner must be at fault. Consider Figure 9.14 which is a diagrammatic illustration of the pick-up triangle formed when no seam interaction is used. The base corner of the triangle is formed by the intersection of the pick-up yarn and the loop yarn. In this configuration the position of the loop yarn is controlled by the grabber but the pick-up yarn position is controlled by the yarn loop \((A)\) (a previously formed loop). This is satisfactory provided there is adequate take-down tension and even if the yarn loop \((A)\) had not been formed (due to a prior dropped stitch), the pick up yarn would still lie approximately in the same position. Consider now Figure 9.15 which shows diagrammatically the position of the yarn in the knitting zone when a single pitch shog (from left to right) has occurred. It may be observed
FIGURE 9.14

- EYE CORNER
- PICK-UP TRIANGLE
- LOOP CORNER
- LOOP YARN
- PICK-UP YARN
- BASE CORNER
- TAKE-UP TENSION
Figure 9.15

- Direction of Last Shog
- Pick-up Triangle
- Eye Corner
- Pick-up Yarn
- Loop Yarn
- Base Corner
- Take-up Tension
- Yarn Loop 'A'

YARN LOOP 'A'
that the base corner of the pick-up triangle is very accurately controlled by the grabber as both the pick-up and loop yarn are retained by mechanical components. When the needles make the return shog (from right to left) a different element relationship exists (see Figure 9.16). The base corner of the loop yarn is controlled by the grabber as before, but the pick-up yarn is now controlled predominantly by the yarn loop 'A'. The take-down tension, which controls the position of loop 'A', is transmitted from the take-down rollers via several courses of knitted fabric. Therefore, it cannot be guaranteed that every yarn loop 'A' along the width of the machine is in exactly the same relationship (i.e. it may be higher or lower than that drawn in Figure 9.16) and thus the position of the base corner will be affected. This possible defect requires further investigation under single pitch seam interaction conditions, but it could explain the random failures that occur.

9.6.5 Position of the Pick-up Triangle

Under perfect conditions the pick-up needle cannot fail to pick up the yarn. Obviously, perfect conditions will not prevail and hence the picking-up needle has been designed to have a considerable spatial positional tolerance with respect to the pick-up yarn. The tolerance may in fact be at the limit of acceptability such that failures occur randomly as the pick-up yarn or base corner is formed outside the tolerance band. To increase the tolerance an attempt was made to move the base corner closer to the picking-up needle just prior to the yarn pick-up. This was achieved by studying the grabber motion which, at that stage in the cycle is retracting leaving the knitted loops behind. The root corner of the grabber
Figure 9.16

- **DIRECTION OF LAST SHOG**
- **PICK-UP TRIANGLE**
- **PICK-UP YARN**
- **BASE CORNER**
- **LOOP YARN**
- **TAKE-UP TENSION**
- **YARN LOOP A**
was undercut slightly to allow yarns to slip into a groove (see Figure 9.17). Thus, as the grabber started to retract it brought the fabric, and consequently the base corner, to the picking-up needle. There was a noticeable improvement in the reliability achieved with this grabber modification but the 100% reliability target was still not attained. A further movement of the base corner into the picking-up needle was not possible by this method because a retraction of the modified 'hooking' grabber brought the loop corner forward as well. It was previously stated that the loop corner has always been well clear of the picking-up needle, but with the modified grabber this clearance has been reduced to a narrow margin of acceptability. The conclusion to be drawn from this experimentation is not necessarily that future designs should include a hooked grabber, but that the base corner is not always positioned consistently under continuous running conditions.

9.6.6 Accuracy of Elements

All the above postulations regarding the occurrence of random stitch failures are based on the accuracy of formation of the picking-up triangle. However, it has been noted that a large proportion of the knitted seams (approximately 50%) have never dropped a stitch for the duration of the experiments (which represented about 20 m of fabric production). The laws of probability dictate that if the dropped stitches did occur randomly then a much larger number of faulty seams should have been apparent by this stage, and this observation suggests that the accuracy of alignment of the knitting elements (both needle and grabber) was inadequate. The principle of the new fabric process was directed towards producing a system requi-
PLAN 'X'

ALL DIMENSIONS IN MM
SCALE=10 : 1

FIGURE 9.17
ring non-critical alignments and indeed the pitch spacings of adjacent needles and their points were inconsistent. Originally this inaccuracy was thought to be within the design tolerance, but if the pick-up triangle is occasionally being formed inaccurately, for the reasons postulated above, then a well-aligned needle might still pick up the loop whilst a poorly-aligned needle might miss it. Hence the resulting fabric reveals several continuous perfect seams produced by well-aligned needles picking up both accurately formed and inaccurately-formed triangles; whilst random faults occur on seams where poorly-aligned needles pick up the accurately-formed triangles and miss the inaccurately-formed ones. In order to investigate this possibility further, needle banks should be manufactured to a tolerance that is more precise, but still commercially acceptable.
CHAPTER 10

SUMMARY OF THE WORK TO DATE

10.1 Textile Aspects

The actual size experimentation conducted to date suggests that the graphically enumerated range of the novel structures (see Chapters 4 and 5) ought to be practicably realisable. The novel process and some of its structures (see Figure 10.1) have been demonstrated in confidence to some textile manufacturers and their subjective assessments have been very favourable. Various uses for the envisaged products have been proposed, particularly where their novelty aspects may be exploited; e.g. novelty fashion outerwear, furnishing, industrial and surgical fabrics etc. or as rapidly produced novel tricot fabrics of medium and heavy weights.

The 'Basic' and 'Alternative' type structures are both of novel configuration (similar to a Waltex structure only); in addition the 'Basic' structure is identical on both sides, i.e. it has no face and reverse sides as is usual for tricot fabrics. Conversely, for all structure variants, the 'Alternative' type fabric exhibits a face side (Figure 10.2a) and a different reverse side (Figure 10.2b).

Any specification of fabric weight is not considered appropriate at this stage of the development because the structure is unique; the only reasonable basis for comparison might be an openness ratio for looped fabrics.
10.2 Engineering Aspects

A range of structures of the 'Alternative' type (see Section 3.3) has been produced on the powered research rig (Figure 10.3) at machine speeds exceeding 600 revolutions per minute. This corresponds to effective production rates of more than 1200 knitted courses of loops per minute, i.e. equivalent to the current maximum speeds of the commercial 'high-speed' tricot machines (see Section 2.6). These production rates have been reached using staple-spun acrylic (Courtelle) yarns and there is no indication of these yarns approaching their breaking stress limits. Running speeds to date have been limited solely by the light-weight nature of the powered research rig and it is confidently estimated that design speeds ought to be at least doubled for the prototype machine.

As is usual with pilot work of this kind, many aspects previously thought to be of minor importance, and others not even suspected, now stand out as important subjects for further investigation. It is submitted that in this thesis, the major emphasis has been directed to the engineering aspects of the work in general and to process performance reliability in particular. It is the author's assessment that a still higher reliability of the basic looping ought to be attained before the process could be considered for industrial exploitation.

The powered research rig performed its functions satisfactorily. Moreover, the basic design speeds were even exceeded for the simpler forms of structures; thus similar design concepts might usefully be followed in the design of the prototype machine. However, the needle and grabber shogging motions were the first to falter, and these could also account for some of the mis-picked loops. The light-
FIGURE 10.2

(a) FACE VIEW

(b) REAR VIEW
weight design of the drives between the needle shafts and the shogging module permits excessive back-lash thereby resulting in occasional misalignment of the Z-motion to the primary orbit (see Section 9.2).
CHAPTER 11

PROPOSALS FOR FUTURE WORK

11.1 Textile Aspects

In the current international awareness of diminishing resources, savings in materials and/or energy must be of utmost priority. Higher production rates and novelty of appearance could be adequate to launch a new process, although, its ultimate success would depend on the total gain, some of which might be unforeseen at this stage, e.g. savings in yarn costs. Therefore much more needs to be learned regarding the textile aspects of this work which is not conveniently studied with the resources of most mechanical engineering teaching establishments. However, on a shorter term basis, to facilitate the design of a successful prototype machine, the potentially most promising structures ought to be identified and grouped because to design a fully general purpose machine to make all these structures might prove to be impracticable.

Many more fabrics should be manufactured using different yarn and structure permutations (see Chapters 4, 5 and 6) to facilitate the scientific evaluation of their characteristics and physical properties; these are the main ingredients to be considered by any potential user of the process.

11.2 Engineering Aspects

Assuming that the process is not to follow an unforeseen radically changed direction, it is the author's opinion that further optimisation ought to be conducted via development of the powered
rig to perfect the 'pick-up' or 'looping' reliability before finalising the design of a prototype machine. The following suggestions for future work are based on observations made during the most recent experimentation.

11.2.1 Needle Design

The research rig to date has been fitted with modified 'Loc-stitch' needles merely for expediency. However, experiments have shown that a specially designed needle would considerably improve the reliability of the process. Figure 11.1 shows (in two orthographic views) an arrangement of a pair of proposed needles having the following innovations:

i) The depth of the needle is increased to 1.7 mm. This allows a larger eye to be used, which ought to facilitate one of two advantages; either larger knots or slubs should be knitted more successfully, or, for the same needle gauge (2.2 mm), coarser yarns could be used, to produce denser fabric constructions.

ii) The distance from the needle point to its eye is reduced to increase the presentation of the pick-up yarn to the pick-up needle (see Figure 11.1).

iii) Immediately beyond the eyes 1 and 2, Figure 11.1, the needles are relieved to approximately 1.1 mm depth, in an attempt to bring the pick-up needle 3 in a closer proximity to the pick-up triangle 4, before it is shogged to pick up the yarn 5. It may be seen (Figure 11.1) that the base corner 6 would now have to be severely displaced for a pick-up failure to occur.
SECTION 'A-A'

ADDITIONAL TOLERANCE
FOR PICK-UP YARN

PLAN 'X'

SCALE=10:1
FIRST ANGLE PROJECTION

FIGURE 11.1
iv) Because only the top flank of the needle is active in the picking-up process the point 7 could be moved to the top and to one side of the flank. This should provide a better angular relationship between the interacting elements.

v) It is proposed to move point 9 on needle 8 to an identical position as on needle 3, Figure 11.1, thus facilitating the use of some needles and grabbers on both sides of the machine.

vi) It is further proposed to relieve the needles at 10 and 11. This ought to shield the suspended pick-up yarn 12 from the dragging effect of the sliding loop 13, Figure 11.1.

11.2.2 Needle Primary Orbit

It is considered that little change in the needle primary orbit would be required since this forms the datum around which all the other elements and their motions are designed. However, the time during which the needle bank is retracted clear of the pick-up yarn could be increased slightly because this is the period allowed for the seam interaction shog. With the research rig in its present form this period of time is insufficient to allow the needles to shog more than two pitches (i.e. 4.4 mm) in either direction.

11.2.3 Needle Shogging Motion

The shogging necessary for seam interaction has been discussed above (Section 11.2.2), but due to the proposed new shape of needle points and the overriding need for performance reliability, the pick-up shogging ought to be optimised still further. However, because identical needles are used on both sides of the machine, the two motions will also be the same.
11.2.4 **Grabber Design**

The simplicity of the new process is impaired by the need for the grabber nose to lie across the flank of the needle. It has been observed on the research rig that this function of the grabber is indeed necessary and it performs the function very well; therefore, the author can see no alternative to the cranked-needle and angled-grabber configuration. Moreover, the grabber ought to be designed to perform the second, hitherto overlooked, function of stitch-length setting. In general all needles generate the same loop lengths during all cycles, but the knitted course density is varied by the amount of back-robbing. To a limited extent this could be controlled as a function of the fabric take-down tension, but it should be achieved more reliably, and with the utilisation of lower fabric and yarn tensions, if it was set against the nose of an accurately set grabber element.

11.2.5 **Grabber Motions**

The existing grabber motions on the research rig are basically satisfactory and only minor changes are envisaged. During the time that the grabbers are holding the base-corner of the pick-up triangle, they could be shogged further to increase the angle between the needle flank and the pick-up yarn in the Z direction (see Figure 11.2). This ought to further assist the pick-up needle to collect its yarn.

11.2.6 **Prototype Machine**

All the above-mentioned proposals will have abearing on the design of the first prototype machine. However, the change to the use of identical needles on both sides of the machine (see Section 11.2.1(v)) is
FIGURE 11.2
of paramount importance. Regarding the textile aspects, this change would represent the limiting of the process to the generation of the 'Basic' type structures only. From the engineering viewpoint, such identical elements would represent a substantial simplification and the machine would thereby be a better operating prospect at its introduction in industry. Moreover, the present undesirable need for twist-matching (see Section 9.6.1) for the yarns on each side of the machine would be obviated.

Most concerted effort should be subjected to the design of the shoggling motions and the shogged mass inertias\(^3\). The flexible struts\(^3\) used for the author's rig\(^1\) and Vine's machine\(^10\) are ideal in applications for light loads and small oscillations when three-dimensional motions are required, yet the buckling strength and fatigue life of such struts must be thoroughly investigated.
CHAPTER 12

CONCLUSIONS

The author and his colleagues consider the novel process and its products to be of substantial industrial merit and commercial potential. A similar conclusion would seem to have been reached by The National Research and Development Corporation, in that it is currently securing patent protection with a view to offering this new product to British industry. Moreover, a considerable wealth of understanding has been obtained regarding the many factors influencing this form of yarn manipulation by simplified elements. The author is very gratified that this development is continuing via further S.R.C. support, thus providing application for some of the unreported knowledge also. Thus it is submitted that the stated objects of the thesis (Section 1.3) have been fully accomplished.
REFERENCES


26. 5th International Textile Machinery Exhibition, 1967, Basel, Switzerland.


29. Karl Mayer Textilmaschinenfabric GmbH, Germany, Trade Literature.


APPENDIX 1

A TYPICAL 'GINO' DRAWING PROGRAMME FOR DRAWING THE 'BASIC' SEAM

SEND TO (EV, SEMICOMPUSER, AXYZ)
DUMP ON (EV, PROGRAM USE)
WORK (EV, WORKFILEUSER)
RUN
LIBRARY (EV, SUBGROUPGINO)
PROGRAM (P.KOB)
COMPRESS INTEGER AND LOGICAL
INPUT 1,5=100
OUTPUT 2,6=LPV
TRACE 2
FND

MASTER TIME AST
CALL LU:1934
CALL DEVPAP(700,700,1)
CALL WINDW(3)
CALL SHIFTC(100,100)
CALL SCALE(0,5)
CALL SUVE
CALL SHIFTC(100,0)
CALL ROTAT5(2,70)
CALL SUVE
CALL ROTAT5(2,270)
CALL SHIFTC(100,0)
CALL TRAFNC
CALL AXON3(-200,100,200)
CALL SUVE
CALL TRAFNC
CALL SHIFTC(-200,800)
CALL SCALE(0,4)
CALL SUVE
CALL SHIFTC(125,0)
CALL ROTAT5(2,70)
CALL SUVE
CALL ROTAT5(2,270)
CALL SHIFTC(125,0)
CALL TRAFNC
CALL AXON3(-200,100,200)
CALL SUVE
CALL TRAFNC
CALL SHIFTC(-250,700)
CALL SCALE(0,5)
CALL SUVE
CALL SHIFTC(250,0)
CALL ROTAT5(2,70)
CALL SUVE
CALL ROTAT5(2,270)
CALL SHIFTC(250,0)
CALL AXON3(-200,100,200)
CALL SUVE
CALL DEVENU
STOP
END OF SEGMENT, LENGTH 187, MAPI ZIMEAST
SUBROUTINE SUVE
  CALL RINDA
  CALL SHIF (0.0, 32.0, 0.0)
  CALL ROTAI S(2,180.0)" \n  CALL DASHED(1.4, 0.2, 5.0, 0.0)
  CALL RINDA
  CALL DASHED(0.1, 1.1, 1.1)
  CALL ROTAI S(2,180.0)
  CALL SHIF (0.0, -32.0, 0.0)
  RETURN
END

SUBROUTINE RINDA
  CALL CILPA
  CALL SHIF (0.0, 84.0)
  CALL CILPA
  CALL SHIF (0.0, 84.0)
  CALL CILPA
  CALL SHIF (0.0, 84.0)
  CALL CILPA
  CALL SHIF (0.0, 336.0, 0.0)
  RETURN
END

SUBROUTINE CILPA
  CALL MOVUS(6, 0, 0, 0)
  DTX=1.8
  DTY=5.0
  DTZ=5.0
  CALL ARCTUS(-6.04, 5.64, 0.0)
  CALL LINTUS(1.504, 24.83, 3.0)
  DTX=5.0
  DTY=5.0
  DTZ=5.0
  CALL LINTUS(-6.0, 5.64, 0.0)
  RETURN
END
APPENDIX II

A TYPICAL 'GINO' DRAWING PROGRAMME FOR
DRAWING THE 'ALTERNATIVE' SEAM

0001 SEND TO (ED, SEMICOMPUSER.AXXX)
0002 DUMP ON (ED, PROGRAM USER)
0003 WORK (ED, WORKFILEUSER)
0004 RUN
0005 LIBRARY (ED, SUBGROUP GINO)
0006 PROGRAM (PRIO)
0007 COMPRESS INTEGER AND LOGICAL
0008 INPUT 1, 5 = CWP
0009 OUTPUT 2, 6 = LPO
0010 TRACE 2
0011 END

0012 MASTER ALTE SEAM
0013 CALL LINJ54
0014 CALL DEPAP (700, 7W, 71)
0015 CALL WINDOW (3)
0016 CALL SHFT (100, 100, 100)
0017 CALL SCALE (0, 5)
0018 CALL SUF
0019 CALL SHFT (100, 0)
0020 CALL ROTAT3 (2, 9V)
0021 CALL SUF
0022 CALL ROTAT3 (2, 0, 0)
0023 CALL SHFT2 (100, 0)
0024 CALL TRAREG
0025 CALL AXUN3 (-200, 100, 200)
0026 CALL SUF
0027 CALL TRAFEND
0028 CALL SHFT2 (-20V., 0, 0)
0029 CALL SCALE (0, 4)
0030 CALL SUF
0031 CALL SHFT2 (125, 0)
0032 CALL ROTAT3 (2, 9V)
0033 CALL SUF
0034 CALL ROTAT3 (2, 200)
0035 CALL SHFT2 (125, 0)
0036 CALL TRAREG
0037 CALL AXUN3 (-200, 100, 200)
0038 CALL SUF
0039 CALL TRAFEND
0040 CALL SHFT2 (-25V, 0, 0)
0041 CALL SCALE (6, 5)
0042 CALL SUF
0043 CALL SHFT2 (250, 0)
0044 CALL ROTAT3 (2, 9V)
0045 CALL SUF
0046 CALL ROTAT3 (2, 200)
0047 CALL SHFT2 (250, 0)
0048 CALL AXUN3 (-200, 100, 200)
0049 CALL SUF
0050 CALL END
0051 STOP
0052 END

END OF SEGMENT, LENGTH 187, NAME ALTESEAM
0053  subroutine suve
0054  call rindal
0055  call shift3(0., 42., 0.)
0056  call rotats(2, 160.)
0057  call dashed(1, 4, 0, 4, 5, 0, 0)
0058  call rindal
0059  call dashed(0, 1, 1, 1, 1)
0060  call rotats(2, 160.)
0061  call shift3(0., -42., 0.)
0062  return
0063  end

end of segment, length 61, name suve

0064  subroutine rindal
0065  call cildp
0066  call laidar
0067  call shift2(0., 84.)
0068  call cildp
0069  call laidar
0070  call shift2(0., 84.)
0071  call cildp
0072  call laidar
0073  call shift2(0., 84.)
0074  call cildp
0075  call laidar
0076  call shift2(0., 84.)
0077  call cildp
0078  call laidar
0079  call shift3(0., -336., 0.)
0080  return
0081  end

end of segment, length 75, name rindal

0082  subroutine rindar
0083  call cildp
0084  call laidar
0085  call shift2(0., 84.)
0086  call cildp
0087  call laidar
0088  call shift2(0., 84.)
0089  call cildp
0090  call laidar
0091  call shift2(0., 84.)
0092  call cildp
0093  call laidar
0094  call shift2(0., 84.)
0095  call cildp
0096  call laidar
0097  call shift3(0., -336., 0.)
0098  return
0099  end

end of segment, length 75, name rindar
SUBROUTINE CILPA
CALL MOVTO3(6.,0.,0.,)
DTX=1.0
DTX=5.0
DTZ=5.0
CALL ARITS3(R,05,5,64,0..R,05,5,64,6.,DTX,DTY,DTZ)
CALL LINTO3(15,04,64,5,3,1)
DTX=5.0
DTY=5.0
DTZ=5.0
CALL ARITS3(0..R,05,5,64,0..R,05,5,64,6..DTX,DTY,DTZ)
CALL LINTO3(-8,05,5,64,5,0)
DTX=1.8
DTY=5.0
DTZ=5.0
CALL ARITS3(-8,05,5,64,0..R,05,5,64,6..DTX,DTY,DTZ)
RETURN
END

END OF SEGMENT, LENGTH 177, NAME CILPA

SUBROUTINE LAIPAL
CALL MOVTO3(-6.,0.,0.)
DTX=1.0
DTY=5.94
DTZ=5.64
CALL ARITS3(-5.5,74,6..-5,5,94,-6.,DTX,DTY,DTZ)
CALL LINTO3(5,64,70,85,-6.)
DTX=1.0
DTY=5.94
DTZ=5.94
CALL ARITS3(5,64,70,15,6..84,0.,DTX,DTY,DTZ)
RETURN
END

END OF SEGMENT, LENGTH 97, NAME LAIPAL

SUBROUTINE LAIPAR
CALL MOVTO3(6.,0.,0.,)
DTX=1.0
DTY=5.94
DTZ=5.64
CALL ARITS3(5.64,5.64,0..5.64,5.94,-6.,DTX,DTY,DTZ)
CALL LINTO3(-5.04,78.85,-6.)
DTX=1.0
DTY=5.94
DTZ=5.94
CALL ARITS3(-5.04,78.15,6..84,0.,DTX,DTY,DTZ)
RETURN
END

END OF SEGMENT, LENGTH 101, NAME LAIPAR

FINISH
APPENDIX III

Specification of Major Bought/Out Transmission Equipment

(a) Prime Mover:

Make - G.E.C. Machines
Model - Kapax Induction Motor
Size - D100J  No. LE2305  1405S
KW - 3  ph - 3
rev/min - 1440  Hz - 50
V220-250/380-440
A 10.5/6.1  Rtg. - Cont.
Brgs. - DE6206Z  NDE 6206Z
Diag. - 5  Ins. - Class B

(b) Drive Speed-Variator:

Make - Carter Gears Limited
Model - Hydraulic Infinitely Variable Speed Drive
Size - F14/17851
Input power - 2.3 KW
Input speed - 960 rev/min

Infinitely Variable
Maximum Forward Speed - 960 rev/min

Output Speed
Maximum Reverse Speed - 960 rev/min

Output Power at Maximum Speed - 1.9 KW

(c) Main-Drive Clutch:

Make - Dyna-torQ Clutch, Eaton Corporation
Model - Dyna-torQ Electromagnetic Clutch - 308
Overall dia. - 232 mm.
(c) Continued

Static Torque - 170 Nm
Actuation - 90 volt D.C.

(d) Take-up Drive Speed Variator:

Make - Minidrive, Haynau, Munchen
Model - Infinitely variable speed
Type - 2 HW No. 127458297
Watts - 160 (at inp. 1400 min\(^{-1}\))
Outp. - 465 - 4200 min\(^{-1}\)