An Analytical Study of Warp Yarns Tension during the Weaving Process

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Abstract:

Despite the variety of weaving operations, the shed formation and its setting process are considered the most important and challenging operation ever, as it can rightly be considered the cornerstone of the whole weaving process. In this process, the warp yarns are divided into two groups at least (sometimes up to four groups in the carpet as well as narrow weaving machines). One group moves up, forming the upper layer, and the other down to form the lower layer. The created space between the two layers must be clear and clean in the sense that it takes the form of an isosceles triangle so that the warp yarns in each layer are close to each other. The side projection of the two legs of the triangle is two straight pieces, and the base of the triangle creates the shed height and it cannot be otherwise. Although the warp yarns constituting each layer are drawn in at least two heald frames and a maximum of up to twenty frames for the two layers together, the yarns of each layer must be at the same level. This can only be achieved if the tension of the warp yarns of both layers is tightly and completely defined so that the opened shed becomes valid for the weft holder to pass across (with different means of weft insertion) without any obstacles, as well as the homogeneity of the acting forces on the warp yarns during the weaving process. All of this eventually leads to the equality and homogeneity of the tensile strength of the woven fabric as a final product for any purpose of use. This may not have great importance for traditional uses of woven fabrics, but it has a great part of importance, especially in the industrial and technical use of woven fabrics. For all the aforementioned reasons, this research paper sheds the light on this important point in the field of the textile industry, which is the difference in the yarns' tension rates during operations. This is a frequent occurrence in all stages of the textile industries, whether in the different spinning processes and the procedures of weaving preparation such as winding, warping, etc., and the processes of weaving, warp, and weft knitting. The research paper is concerned with the study and analysis of the forces affecting the warp yarns throughout the full cycle of a complete repeat of fabric construction. An analytical research study to determine the reasons for the change in the tension rates affecting the warp yarns. As well as trying to develop applied technical solutions to solve the obstacles that occur during the weaving process, to increase the quality of the woven product under the required quality rates. Clarify and analyze the practical and scientific reasons for this problem, while laying the technical foundations for the possibility of solving it in the future in the next research papers.

Keywords:

Weaving mechanism, warp yarn tension, heald frame, fabric structures, Fabric construction, Weft density, yarn Friction.

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1. Introduction

Weaving is truly one of the oldest extant practices by humans in the world, with a history rooted in the Neolithic period (c. 9000-4500 BC). With the great developments that have occurred in weaving machine techniques since ancient history until now, the fixed element, which has not made any changes, are the five movements of the weaving machine /1/. These movements may have somewhat changed in the way they form, but they did not differ in their principle in terms of time sequence as well as the movement mechanism. These five movements of the weaving process are divided into two parts: the first consists of three primary motions: shed formation, weft insertion, and weft beating-up, and the second consists of two additional motions left off of warp yarns and fabric take-up.

This research paper is concerned with the difference in tension rates of the warp yarns during the weaving operation. This study is very important and necessary in the different textile processes in general, and it is also more important, especially for the weaving operation, and it is the focus of this study. The warp tension has a very important impact on the quality of the weaving and on the required quality rates of the woven fabrics. The warp tension control remained one of the most important elements despite the technical development in the design and manufacture of weaving machines. The tension occurred directly to the warp yarns during the vertical movement of heald frames (shedding), so it was necessary to study the change in tension variations and try to find technical solutions. For this case, the mathematical analysis study of the forces affecting the warp yarns throughout the full cycle of a complete repeat of fabric construction is very important. Whereas the change in the tension values of the warp yarns is related directly to the shed formation process with its three repeated stages: shed opening, shed dwelling, and shed closing ... etc., the behavior of the warp yarns was precisely studied during the shedding process.

Shedding is one of the three primary motions in weaving and is aimed at splitting the warp yarns into two layers, namely the top (or the upper) shed line and the bottom (or the lower) shed line, to form a tunnel known as the shed.

2. Background

2. Types of shed formation

The shed formation represents the first primary motion of the weaving process. By this motion the warp yarns must be divided into two layers, between them the wefts are passed separately through the formed shed. The shedding mechanism affects greatly the vertical movements of the heald frames /2/. These movements depend on two items, the first one is the initial position of the warp yarns at the beginning of the process and the second is the behavior of the movement of the heald during a complete revolution of the weaving machine (360˚).

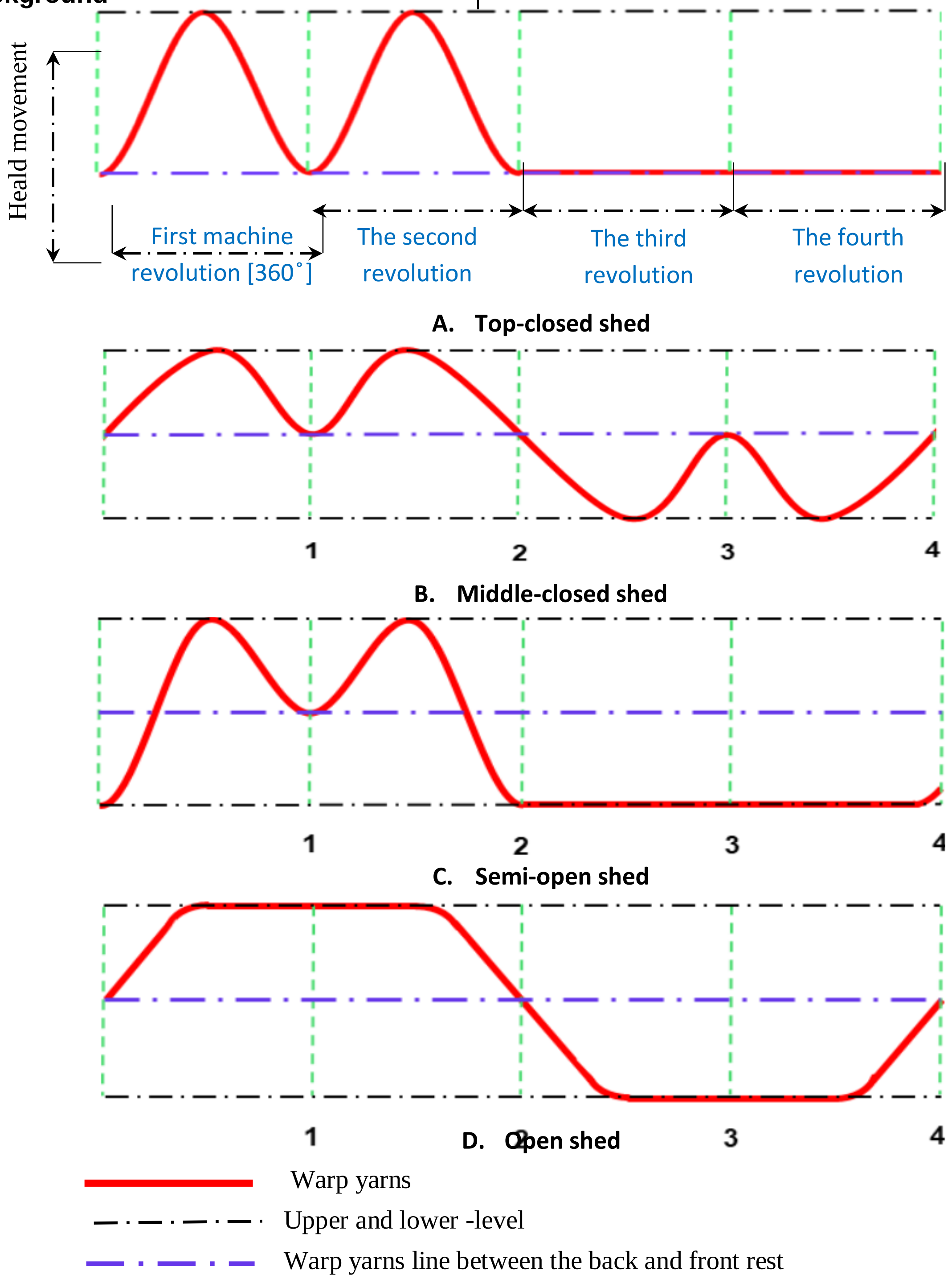


Fig. 1: ***Types of shed formation /3/***

Fig. 1 illustrates the different vertical movements of a heald frame, which must keep the warp yarns in the upper level for two consecutive picks and bring them to the lower level over the next two picks. The resultant curves are plotted as a function that simulates the motion of this heald.

The blue horizontal line represents the warp yarns line between the back and front rest, which represent also the bottom position in case A and the middle position in the other cases. The other two horizontal lines represent the top and bottom positions of the warp layers. On the other hand, the distance between two consequent vertical lines equals one revolution of the weaving machine /3/.

2.1 Top-closed shed

It is the oldest used technique for shed formation, in which the upper layer returns to the bottom position to form a closed shed after every pick as illustrated in Fig. 1A. This method results in a great deal of wasted movement, therefore it affects negatively the rate of production, as there would be in some weave constructions that required warp yarns to be lifted for two or more succession weaving revolutions. According to that, the tension rates on the upper warp layer more than on the lower, hence this unequal warp tension produces poor quality fabrics. Nowadays, this method is used only in old types of dobbies, single-jacquard devices especially in hand weaving looms.

2.2 Middle-closed shed

By using this method, all the warp yarns return to the middle position to form a closed shed after every revolution as illustrated in Fig. 1B. It means that all yarns must be either raised or lowered every pick for any weave construction that leads to a great deal of wasted movement, consequently this method is more suitable for leno fabric weaving. Compared with the previous method, the wasted movement is reduced, and tension is distributed uniformly over all the warp yarns, and it is, therefore, preferable in this respect to the top-closed shed method.

Because of the balanced movement for upper and -lower layers, the middle-closed shed is still used commonly in some forms of tappet shedding, and jacquard machines. Despite a considerable amount of wasted movement which is carried out, due to the return of all yarns to the central plane between successive picks.

2.3 Semi-open shed

In this case, like the top-closed shed, the warp yarns stay up for two or more picks in succession only to the middle position between picks as illustrated in Fig. 1C. There is less wasted movement than in the previous shed types which are shown in Fig. 1 A or C. The warp yarns don't form a single layer between successive picks, but neither does it remain fully open, nor close, but it must be semi-open. In this shed, the stationary lower layer is retained, but the upper layer yarns either pass lower at one movement or are carried to the top mid-way and again carried to the top. This shed can be formed as expeditiously as an open shed for the upward movement of the lower layer, on the other hand, the upper layer moves downward to a semi-open level and then is converted into an upward movement immediately. They all reach the top together but the strain upon them is not equally distributed. The semi-open shed reduced the wasteful movement of yarns as compared to top closed or bottom sheds. The tension of the upper and lower warp yarns is equal, and the machine speed can run at a faster speed. This shed is used widely in dobby and jacquard weaving machines /4/.

2.4 Open shed

As it is illustrated in Fig. 1D, the warp yarns are required to stay up or down for two or more consecutive picks. There is no wasted movement, and the shed doesn't close unless there is a complete interchange in the position of the warp yarns between successive picks.

The tension values of warp yarns on upper and lower layers are equal, which affected positively on the economics of weaving operations. As a semi-open shed, the open shed reduced the wasteful movement of yarns, and the machine speed can run at a faster speed and is used widely in dobby and jacquard weaving machines.

3. Methodology

3.1 <u>Analysis of the Problem</u>

The problem of the research was limited in brief in studying the reasons for the difference in simultaneous tension rates affecting any of the upper and lower layers of the shed during the weaving process.

3.2 <u>Theory of Technology</u>

The technology used in this research depends on:

- The mathematical analysis and the forces affecting the warp yarns throughout the full cycles of the weaving process.
- An analytical research study to determine the reasons for the change in the tension rates affecting the warp yarns.
- Trying to develop applied technical solutions to solve the obstacles that occur during the weaving process to increase the quality of the woven product under the required quality rates.
- Clarify and analyze the practical and scientific reasons for this problem, while laying the technical foundations for the possibility of solving it in the future in the next research

papers.

3.3 Weaving of Standard Experiment Samples

This important part of the research was identified in weaving experimental samples with different elements of fabric structures. The fabric structures were limited in plain 1/1, twill1/2, and satin 5 weaves.

3.4 Laboratory Measurements

The laboratory measurements are limited in measuring warp yarns' tension while the weaving machine is running. The measurement values have been measured by using a digital yarn tension meter (Hans-Schmidt Model: DTSB-500) /2/.

4. Experiments

The ***experiments*** have been ***carried out*** on Dornier rapier weaving machine p2, which was equipped with a dobby device and two warp beams. On the other side, the machine is equipped with up to 24 heald frames.

The experimental works were divided into two phases:

1. Weaving of experimental samples.
2. Measurement of the warp yarns tension during the weaving process.

4.1 Weaving of experimental samples

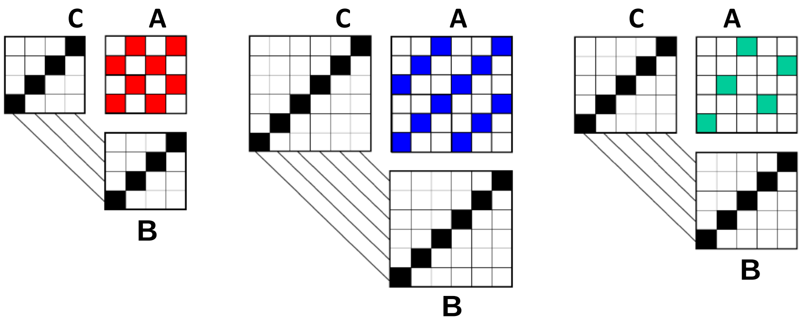
The vital aim of this process is to measure the tension force values affecting the warp yarns during the weaving process. Based on these results, the mechanical force affecting the warp yarn during a complete repeat of woven samples' fabric constructions were determined as represented in Table 1. On the other hand, Fig. 2 shows the design, draft system and lifting plan of the experimental samples.

The main elements of the woven fabric structure variables were:

1- Fabric construction: plain 1/1, twill1/2, and satin 5 weaves.
2- Warp yarns density: 24 yarns/cm.
3- Wefts density: 20, 24 and 28 wefts/cm.
4- Warp and weft yarn material: Intermingled Polyester Textured Yarn denier 300.

Table 1: Structure elements of the experimental samples

<table>
<tr><td rowspan="2">Material</td><td rowspan="2">PES (Texture yarn)</td><td>Count denier</td><td>ε - F_{max} %</td><td>F_{max} Gram</td><td>F_{max} g/den</td></tr>
<tr><td>300</td><td>20.1</td><td>1188</td><td>3.96</td></tr>
<tr><td colspan="6">Experimental samples specification</td></tr>
<tr><td rowspan="6">Fabric</td><td colspan="2">Fabric set
Construction</td><td>Warp density [yarn/cm]</td><td colspan="3">Weft density [weft/cm]</td></tr>
<tr><td colspan="2">Plain 1/1</td><td rowspan="3">24</td><td rowspan="3">20</td><td rowspan="3">24</td><td rowspan="3">28</td></tr>
<tr><td colspan="2">Twill 1/2</td></tr>
<tr><td colspan="2">Satin 5</td></tr>
<tr><td rowspan="2">Cover factor</td><td>Warp/weft</td><td>14.4</td><td>12</td><td>14.4</td><td>16.8</td></tr>
<tr><td>Fabric</td><td></td><td>20.52</td><td>21.53</td><td>22.68</td></tr>
</table>



A: Weave diagram (Design)
B: Draft system
C: Lifting (Pegging) plan

Plain 1/1 **Twill 1/2** **Satin 5**

Fig. 2: The weave diagram, draft system and lifting plan of the experimental samples

4.2 Measurement of the warp yarns tension during the weaving process

The laboratory measurements are limited in measuring warp yarns' tension while the weaving machine is running. The measurement values have been measured by using a digital yarn tension meter (Hans-Schmidt Model: DTSB-500) /5/.

The tension values of a single warp yarn have been individually taken. These values were extracted from the diagram curves of the digital yarn tension meter. They were identified at four important points during the complete revolution of the weaving machine (360°).

These four points were:

1- The stability of the warp yarn in the upper layer of the shed,
2- The stability of the warp yarn in the lower layer of the shed,
3- Closed shed, when all the warp yarns are at the same level at the centre point between upper and lower level,
4- Finally, at the weft beat-up point.

Table 2 represents the different values of warp tension for a single warp yarn of the third heald frame. These values have been measured at the centre point of the third heald frame. The tests were achieved for all the experimental samples during weaving according to their woven structural variables which were mentioned before.

Table 2: The tension force for a single warp yarn of heald frame number 3

Fabric Construction	Weft density **[weft/cm]**	**Warp Yarn Tension [cN]**			
		At opened shed		At the center closed shed	at beat-up
		Upper layer	Lower layer		
Plain 1/1	**20**	58	50.3	20.4	88.7
	24	60.2	52.4	21.2	92.1
	28	62.8	53.9	22	95.3
Twill 1/2	**20**	49.7	42.3	19.2	75.4
	24	51.8	44.5	19.7	78.5
	28	53.4	45.8	20.4	81
Satin 5	**20**	42.7	36.7	17	64.5
	24	44.1	38.1	17.6	67.6
	28	45.9	39.2	18.1	69.5

Table 3 represents the different values of warp tension for a single warp yarn of the heald frames 1, 2, 3 and 4 for the plain weave 1/1. These values have been measured at the center point of the heald frames. The tests have been achieved for all the plain weave 1/1 experimental samples during weaving according to their woven structural variables which were mentioned before.

Table 3: The tension force for a single warp yarn of plain weave 1/1 in heald frames

Fabric Const.	**Heald frame**	Weft density **[weft/cm]**	**Warp Yarn Tension [cN]**			
			At opened shed		At the closed shed	at beat-up
			Upper layer	Lower layer		
Plain weave	**1**	**20**	57.6	50.1	20.3	88.5
		24	60.1	52.2	21.2	91.5
		28	62.7	53.2	21.6	95.2
	2	**20**	57.8	50.3	20.3	88.7
		24	60.2	52.2	21.2	91.6
		28	62.7	53.5	21.8	95.2
	3	**20**	58	50.3	20.4	88.7
		24	60.2	52.4	21.2	92.1
		28	62.8	53.9	22	95.3
		20	58	50.3	20.4	88.8
		24	60.5	52.5	21.3	92.2

1/1	**4**	**28**	62.9	54	22	95.3

5. Results and discussions

5.1 Analysis of the measurement results

According to results in tables 2 and 3, it was concluded that the average rates of warp tension for all samples were as follows:

1- The highest values were at the beat-up point, followed by similar values during dwelling shedding, with a big difference; the lowest values of warp tension were at the closed shed as shown in Fig. 3.

2- The values during dwelling shedding for warp yarns of the upper shed were greater than similar values of the lower shed as shown in Fig. 4, with an average value of 16%.

3- The highest values were achieved by using plain weave 1/1 followed by twill weave 1/2, which decreased by 16.4%. On the other hand, the satin 5 weave carried the lowest values by a 35% decrease than plain weave 1/1.

4- The lowest values were achieved by using 20 weft/cm as weft density, but these values increased by 4% according to the increase in weft density with 24 wefts/cm, and 7.5% with 28 wefts/cm.

For the plain weave individually in Fig. 5:

5- The lowest values were achieved by using 20 weft/cm (weft density), but these values increased by 3.9% according to the increase in weft density with 24 wefts/cm, and 7.5% with 28 wefts/cm. These results are like the general results which are discussed above.

6- And also, the results increased gradually from the first heald frame to the second, the third and the fourth heald frame. The increasing values were very slight; it was 0.2% more for the yarn tension in the second heald frame than the similar value in the first heald frame, 0.45% for the third one and 0.6% for the fourth.

5.2 Discussion results analysis

From practical and theoretical points of view, it was found that the differences in results related to the effects of some factors. These factors obviously affected the results, which can be limited in the next points:

1. The positions of heald frames during a revolution of the weaving process
2. The woven fabric structures are divided into two types:
   2.1 Fabric construction
   2.2 Weft density
3. The arrangement of heald frames on the weaving machine

5.2.1 The positions of heald frames during a revolution of the weaving process

The highest values of warp yarn tension were at the beat-up point, owing to the dynamic force of the reed during its forward movement. This force affects the inserted weft which occupies 0.5 mm in the longitudinal direction, with a weft density of 20weft/cm., beside the internal friction between the inserted weft and warp yarns as a result of the interlacing between them during the closed shed. Fig. 3 shows the relation between the warp yarn tension force and the position of the heald frame (Nr. 3) during a revolution of the weaving machine (360°). Furthermore, values of yarn tension were greater for the upper level than the lower level of the dwelling shed affected by the upper height of heald frames, which were more than the lower height of heald frames from the warp yarns line as shown in Fig. 4.

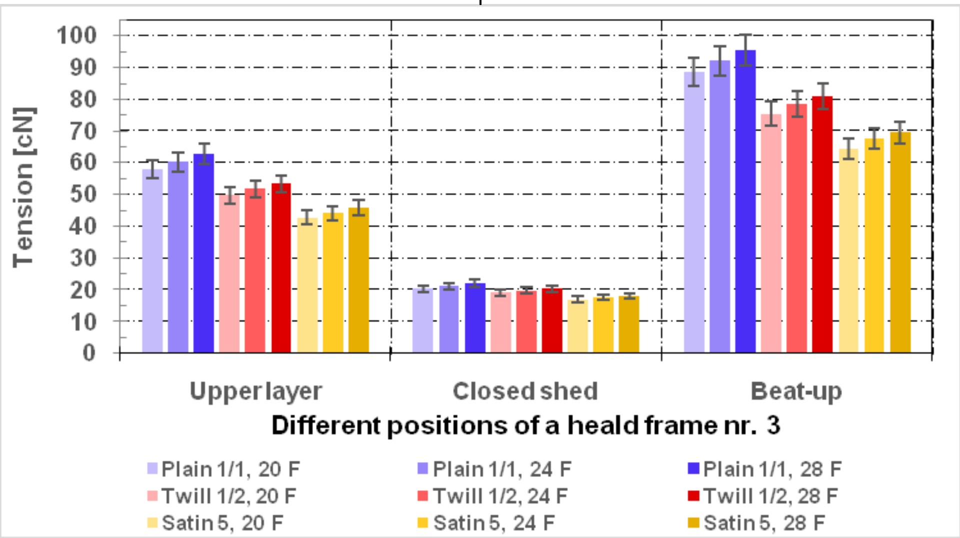


Fig. 3: The relation between the warp yarn tension force and the position of the heald frame (Nr. 3) during a revolution of the weaving machine (360°).

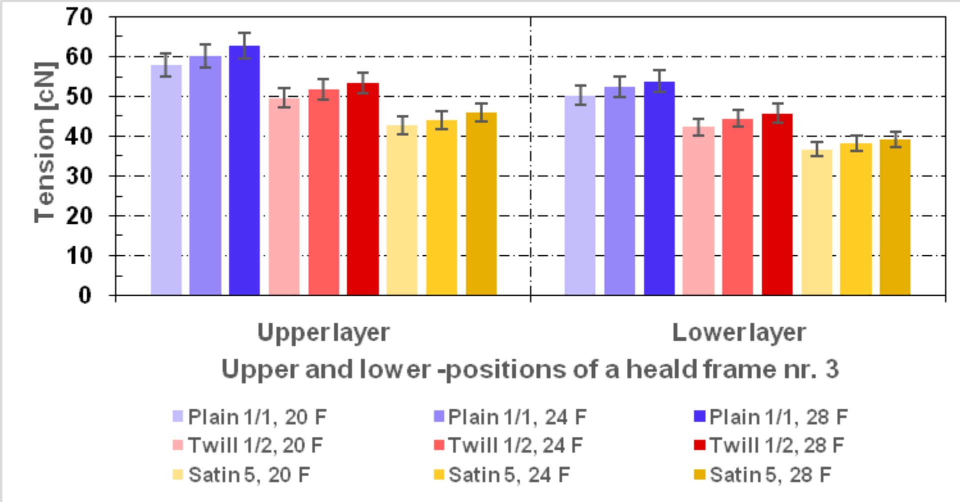


Fig. 4: A comparison of the relation between the warp yarn tension force in the upper layer and the lower layer of the heald frame (Nr. 3) at the same time.

5.2.2 The woven fabrics structures

5.2.2.1 Fabric construction

The highest values of warp yarn tension were achieved by using plain weave 1/1 which was 16.4% more than twill weave 1/2, and 35% more than satin 5 weave. These results related to greater interlacing values between warp and weft yarns in plain weave 1/1 more than any other fabric construction, as shown in Fig. 2. It is woven by passing each warp yarn alternately over and under each weft, these frequent interlacing causes more stability and crimp ratios between yarns and wefts.

On the other side, the twill and satin weaves have fewer interlacing, equal 66.67% and 40% sequentially compared with plain weave 1/1. All that is due to less intersection friction between yarns and wefts, therefore less effect on warp yarns tension.

5.2.2.2 Weft density

The lowest values of warp yarn tension were achieved by using 20 weft/cm, increased by 4% and 7.5% with 24 wefts/cm, and 28 wefts/cm sequentially. That effect is due to smaller distances between successive wefts as a reverse effect of increasing the weft density consequently. Furthermore more intersection friction between yarns and wefts, and therefore more effect on warp yarns tension.

5.2.3 The arrangement of the heald frames on the weaving machine

The results increased very slightly as shown in Fig. 5 from the first heald frame gradually to the fourth heald frame. It was 0.2%, 0.45%, and 0.6% more for the warp yarns' tension values from the first to the fourth heald frames sequentially. This ensures that the increase in height rates of the back heald frames compared with the front ones wasn't very effective in increasing the warp yarns' tension values.

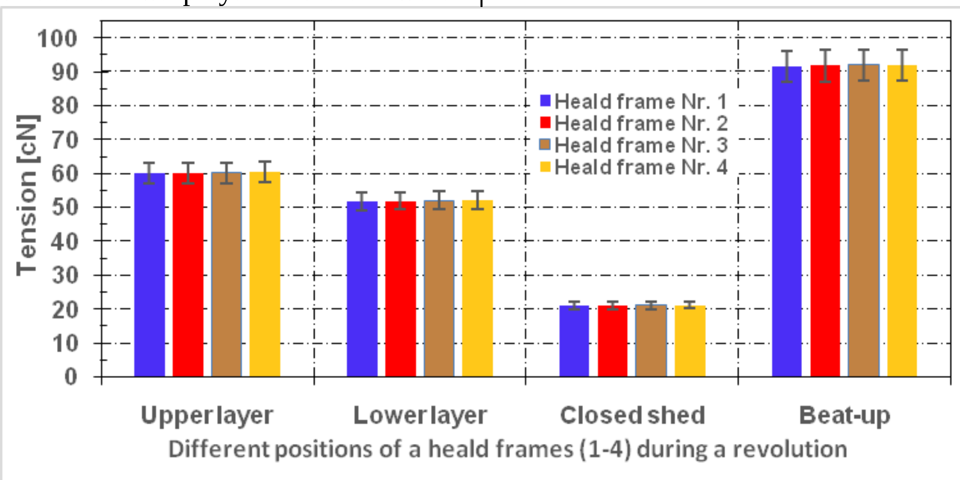


Fig. 5: The relation between the warp yarn tension force in different points for plain weaves 1/1 and the positions of heald frames from numbers 1 to 4.

6. Conclusions

The shed formation process is considered the most important and challenging operation in the weaving process ever. In this process, the warp yarns are mostly divided into two groups, forming the upper layer, and the lower layer. The created space between the two layers must be clear and clean. This can only be achieved if the tension of the warp yarns of both layers is tightly and completely defined so that the opened shed becomes valid for the weft holder to pass across. All of this eventually leads to the equality and homogeneity of the tensile strength of the woven fabric as a final product for any purpose of use.

This research paper sheds light on this important point in the field of textile industries, which is the difference in the yarns' tension rates during operations. This is a frequent occurrence in all stages of the textile industry, especially the weaving process.

The research paper is concerned with the study and analysis of the forces affecting the warp yarns to determine the reasons for the change in the tension rates affecting the warp yarns. it was found from the results that the warp yarns' tension is extremely influenced by the positions of heald frames during a revolution of the weaving process. It is also noted worthily influenced by woven fabric structures (Fabric constructions - Weft density). The slight effect was the arrangement of the heald frames on the weaving machine.

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