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Yarn Tension and Oscillation in the Process of Warp Knitting

Abstract
In the knitting process on Rachel warp knitting looms, yarn tensioning and oscillation in the knitting and compensational zones of the machine are very important; the phenomena should be investigated and the process controlled, especially considering the recent increase in working speed and the growing use of man-made threads. The tensioning and oscillation of yarn were investigated by us directly on a machine at working speeds of 8.5 min^{-1} and 580 min^{-1} with the use of special gauges. We observed changes in yarn tensioning and oscillations in the cycle of loop forming and in the compensational zone, in these particular phases of the process in which the increase of the resistance of unwound warp caused unequal tensioning and oscillation of the yarn, which in turn have a negative influence on the quality and structure of the knitted fabrics as manufactured.

Key words: *warp knitting, knitting zone, compensational zone, yarn tensioning, yarn oscillation, tensioning mechanism.*

Introduction

Warp tension

Warp tensioning in precise knitting machines ranges from 2 to 6 cN, and in some cases even up to 10 cN [3], whereas in crude machines it is much higher. The change of sensitivity of the warp yarn length in the loop to alteration of warp tensioning is characteristic. Increased warp tensioning forces the loop length to increase considerably as a result of increased tensioning from already formed loops on the new half-loop. Figure 1 shows the loop length dependence on the machine's working speed [2]. We can see that the yarn length in the loop decreases with increased tensioning related to the working speed.

The loop length is usually much smaller than the length of warp drawn off through the positioner over the period of positioner deviation ranging from 6 to 8 mm. Drawing off occurs as a result of warp extension; this leads to multiple loading and pressure relaxation of the warp yarn, which in turn results in a decrease in their strength. That is why warp yarns pass through a tensioning mechanism on their way from the warp beam to the positioner.

Oscillation of the tensioning mechanism

The tensioning mechanism forms a complex dynamic system together with the warp yarn. The complexity of such a system is conditioned by its non-linearity, caused by the dependence of rigidity of some parts of the yarn, of the friction coefficient, and of the mode of mutual action between the yarn and tensioning mechanism on the amplitude of its oscillation. The oscillations of this dynamic system, which cause yarn end racking, determine feeding and consumption of yarn in the loop forming cycle [1].

The oscillation amplitude and yarn deformations increase concomitantly with the machine speed. This usually corresponds to forcing the frequency in the proximity of the resonance frequency of the whole system (tensioning mechanism - warp yarn). In this case, the oscillation amplitude of the tensioning mechanism can increase so much that with its downward move in one part of the cycle, the yarn pressure relaxation can no longer be controlled (that is, when the yarn tensioning falls to zero).

With a further increase of speed, the oscillation amplitude of tensioning should decrease. However this does not happen, because of the increased inertial loading which acts on the yarn from the side of the tensioning mechanism.

Medium yarn tensioning increases at the beginning of the machine's start-up. During the machine's stopping, yarn tensioning somewhat decreases because of increased loading. The transient process will in any case change its character with the change of yarn type and weave, because the friction force in the tensioning mechanism and the elastic characteristic of the yarn depend on them.

Yarn oscillations in knitting process

Free oscillation

Yarn tensioning when decreased to a certain value forms good conditions for the cooling phase. A further decrease in tensioning disturbs the knitting process and negatively reflects yarn structure and quality. This is why it is necessary to consider the conditions of transversal yarn oscillations over machine work and determine the parameters of those

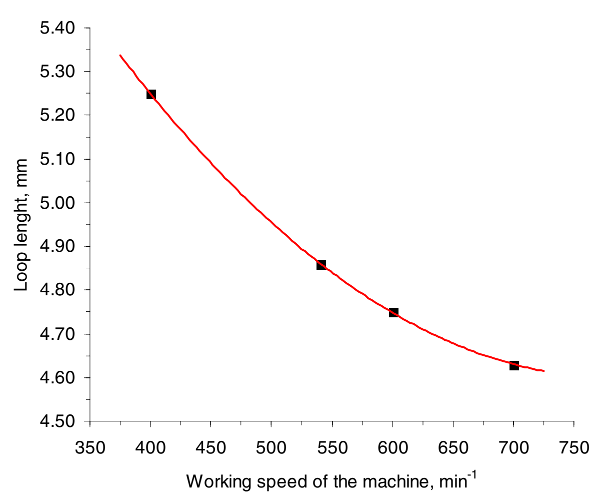

Figure 1. Diagram of loop length dependence on the working speed of the machine.

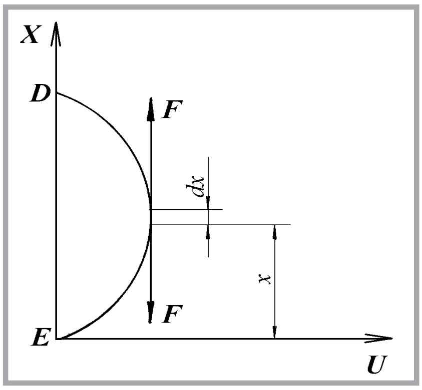

Figure 2. Computing scheme.

oscillations. We will assume that the yarn is absolutely flexible, and that its tensioning force F during pleating is directed tangentially towards the elastic line. We accept that the yarn is also elastic and behaves according to Hook's law during stretching. In addition, the yarn is homogeneous and has a constant count (fineness). The influence of the moving speed along the yarn will be discounted.

We consider a part of the yarn [2] on the section "positioner (guide needle) - latch needle and tensioning mechanism positioner", in a co-ordinate system with point E at the beginning of the co-ordinate (Figure 2). Under the already stated conditions, we will investigate the yarn's move along the abscise axis and how it forms the differential equation of transversal oscillations of yarn stretched between two points.

In the process of yarn tensioning, the value of yarn oscillation of yarn point *u* differs depending upon its co-ordinate *x* and time *t*. At any fixed value of *t*, the diagram based on the *u(x,t)* function determines the shape of the yarn segment oscillations. We will consider an infinitely small part *dx* of the yarn at the DE section. The projection of its ends on the *X* axis will be *x*, *x=dx*. The differential equation for the yarn moving part *dx* will be:

$$m\frac{\delta^2 u}{\delta t^2} = F\frac{\delta^2 u}{\delta x^2}dx \qquad (1)$$

where:
$m=T_t\,dx$ - mass of the yarn segment,
T_t - yarn count, and
F - yarn tensioning force.

Replacing *m* in (4) by T_t and *dx* we achieve:

$$\frac{\delta^2 u}{\delta t^2} = a^2\frac{\delta^2 u}{\delta x^2} \qquad (2)$$

where:
$a=\sqrt{FT_t^{-2}}$ is the speed of transversal waves spread out along the yarn, which depends upon yarn tensioning force.

Expression (2) characterises the free yarn oscillations at a constant tensioning force *F*. In agreement with the Fourier method, the solution of equation (2) can be presented as a product of two functions:

$$U(x,t) = X(x)\,Y(t) \qquad (3)$$

In this case, function *X(x)* depends only on the *x* variable, and function *Y(t)* only on the *t* variable. By differentiation of expression (3) on *x* and *t*, and further replacing it into (2), with separation of the variables, we obtain:

$$\frac{1}{a^2}\frac{\ddot{Y}_{(t)}}{Y_{(t)}} = \frac{\ddot{X}_{(x)}}{X_{(x)}} \qquad (4)$$

The solution of equation (2) of free yarn oscillation, fulfilling the limited conditions, can be written as equation (5). Let us consider the $U_{(x,t)}$ function in the shape of equation (6).

We can see that yarn points do indeed harmoniously oscillate with their free frequencies:

$$\omega = \frac{\pi\,n}{l}a = \frac{\pi\,n}{l}\sqrt{\frac{F}{T_t}} \qquad (7)$$

The first free circular oscillatory frequency of the yarn ω will be:

$$\omega = \frac{\pi\,n}{l} = \frac{\pi}{l}\sqrt{\frac{F}{T_t}} \qquad (8)$$

where:
l - length of the yarn part in (m),
F - yarn tensioning force in (cN),
T_t - yarn count in (g·km^{-1}).

If we express yarn count in tex and take into consideration the acceleration of gravity *g* in m·s^2, then:

$$\omega = \frac{\pi}{l}\sqrt{\frac{10^3 F\cdot g}{T_t}} \qquad (9)$$

$$U_{n(x,t)} = X_{n(x)}Y_{n(t)} = \left(B_{n_1}\cos\frac{\pi\,n}{l}at + B_{n_2}\sin\frac{\pi\,n}{l}at\right)X\sin\frac{\pi\,n}{l}x \qquad (5)$$

$$U_{(x,t)} = A_n\sin\frac{\pi\,n}{l}X\sin\left(\frac{\pi\,n}{l}at+\varphi_n\right) \qquad (6)$$

where: $A_n=\sqrt{B_{n_1}^2+B_{n_2}^2}$ and $tg\varphi_n=\frac{B_{n_1}}{B_{n_2}}$

Equations 5 and 6.

Table 1. *Tensioning and oscillation of the yarn in the loop forming cycle. Remark (comment): Yarn tensioning and oscillation is at positioner - latch needle section.*

Yarn tensioning force F cN	Oscillating frequency ω s^{-1}	Yarn tensioning force F cN	Oscillating frequency ω s^{-1}
0.735	2697	7.350	8528
1.470	3814	7.840	8808
1.715	4119	8.080	8941
4.165	6419	8.820	9342
4.655	6787	9.550	9721
6.860	8239	9.800	9847

Table 2. *Yarn tensioning and oscillation in the compensational zone tensioning mechanism-positioners.*

Yarn tensioning force F, cN	Oscillating frequency, ω s^{-1}
2.00	182
2.14	188
2.25	193
2.94	221

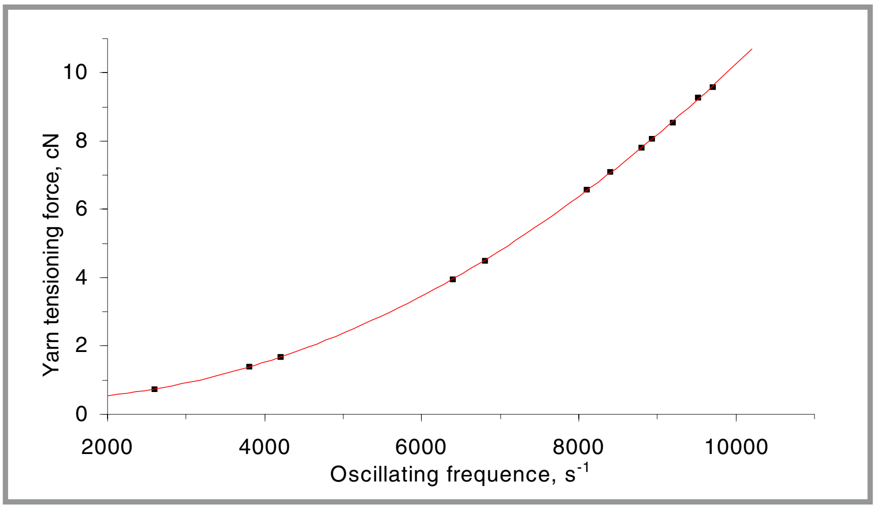

***Figure 3.** Diagram of yarn oscillation in the loop forming cycle in dependence on yarn tensioning force.*

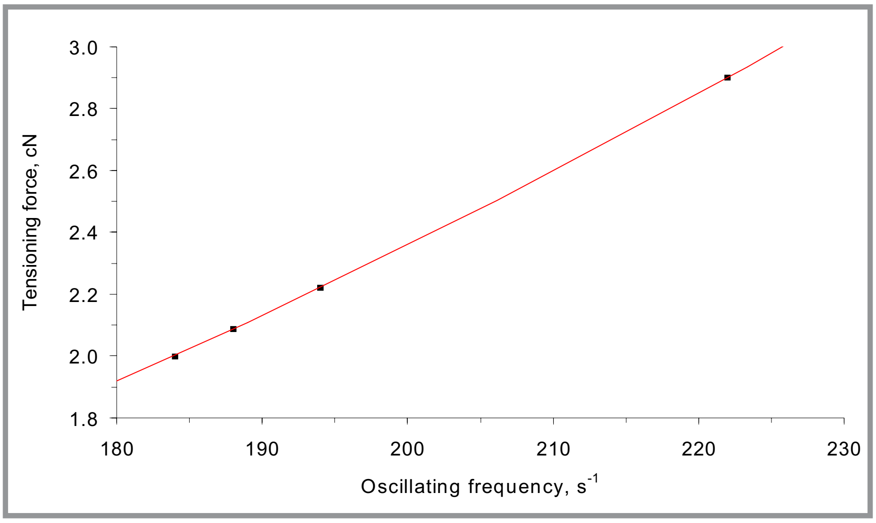

***Figure 4.** Diagram of dependence of yarn oscillations in the compensational zone on the tensioning force.*

From (9) it can be concluded that the free yarn oscillations ω depend upon yarn tensioning force F, and are proportional to $\sqrt{Tt}$. According to that fact, yarns with different fineness will have different free frequencies of oscillations. Parts of the yarn of longer length will have smaller free oscillatory frequencies. The frequency of the yarn's free oscillations f (in Hz) will be:

$$f = \frac{\omega}{2\pi} = \frac{49.4}{l}\sqrt{\frac{F}{T_t}} \qquad (10)$$

Experimental

In our work [2] we considered only the first (basic) free frequency of yarn oscillation. The basic free frequencies ω (according to expression 8) of a polyester yarn segment of 0.0223 m length and with linear density 19.53 tex are listed in Table 1 for different values of yarn tensioning, measured at force F over the loop forming cycle. Length l corresponds to the DE length of the yarn segment in Figure 2 at the section from the positioner vent to the head of the latch needle, when it is at the lowest position.

A diagram of yarn oscillation frequency over the loop forming cycle in dependence on yarn tensioning force (based on Table 1) is shown in Figure 3, whereas Figure 4 shows a diagram of the dependence of yarn oscillations in the compensational zone on the yarn tensioning force.

From Tables 1 and 2 it can be seen that the basic free frequency oscillation is much higher for yarn segments of small length, and that it increases with the increase in yarn tensioning force. The frequency value of oscillations depends on the warp yarns' tensioning force. Yarn oscillations in the knitting zone decrease the reliability of the loop forming process. Yarn vibrations in the knitting zone also have a negative influence on the knitted fabric quality: the reliability of thread laying and feeding decrease together with the decrease in the half-loops application during yarn oscillations with amplitudes in the range of the size of the latch needle head.

Conclusions

Based on the experimental data, it was demonstrated that the frequency of oscillation of a polyester yarn with 19.53 tex and 32 filaments is much higher for smaller yarn segments, and becomes higher with the increase in the yarn tensioning force in the compensational and knitting zones of the machine. The free oscillatory frequencies of yarns differ. Yarn sections with longer length will have smaller free oscillatory frequencies, and will depend upon the yarn tensioning force.

The frequency of yarn oscillations differs from cycle to cycle because of the different warp yarns tensioning force which occurs. This phenomenon negatively influences the reliability of the loop forming process. Yarn vibrations in the knitting zone also have a negative influence on the thread quality; the reliability of yarn laying and feeding decrease (together with formation of half-loops) at yarn oscillations with amplitudes of the size within the range of the size of the latch needle head.

With the increase in the machine's working speed, the value of oscillation of the tensioning mechanism racking changes considerably, which leads to corresponding changes in yarn tensioning in the knitting and compensation zones of the machine.

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