Analysis of the Fabric Selvedge Withdrawal Process by the Cloth Beam in a Weaving Loom

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Abstract. The efficiency of fabric take-up mechanisms in weaving looms affects the quality and stability of woven fabric. This study analyzes selvedge withdrawal by the cloth beam, focusing on interactions between the warp threads, fabric, and rigid loom components. Warp threads and fabric are elastic elements subject to tension, bending, and contact forces, while the take-up roller ensures continuous fabric displacement.

A system of differential equations describes the motion and contact interactions along the yarn path, from the warp beam to the roller, with boundary conditions ensuring continuity and force transmission. Solving equations across loom cycle phases reveals stress–strain states under steady and transient conditions. Four critical aspects are examined: (1) the effect of warp stop motion oscillations on thread tension and fabric withdrawal; (2) shed formation's influence on selvedge displacement; (3) weft beating-up effects on warp stress and withdrawal dynamics; and (4) fabric behavior between the fell line and take-up roller. Warp yarns are modeled as elastic elements and the fabric as a cylindrical sheet with fixed edges, reducing the problem to one dimension. Roller contact is treated with elastic friction to predict equilibrium, stress, and slippage, which starts at the contact boundary and grows with tension differences, affected by roller radius, yarn density, extensibility, and feed factor. The model is validated with STB-180 loom tests.

This study provides a theoretical framework for understanding selvedge withdrawal, enabling precise evaluation of fabric displacement. The results offer practical insights for optimizing loom design, improving fabric quality, and preventing operational defects.

Keywords: weaving loom, fabric selvedge, take-up roller.

1 Introduction

The weaving process represents a sophisticated interplay of mechanical components, fiber dynamics, and fabric formation, where the consistency and quality of the resulting textile largely depend on the accurate regulation of warp and weft interactions. A critical element of this process is the handling of the fabric selvedge, particularly its

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extraction from the working area by the cloth beam. The selvedge, as the fabric's lateral edge, is susceptible to distortion, tension fluctuations, and other imperfections that may undermine both the structural integrity and visual quality of the textile. Consequently, understanding the mechanics of selvedge extraction is vital for optimizing loom design, enhancing fabric quality, and minimizing production flaws.

Recent studies indicate that the withdrawal process is governed by the dynamic interplay between the cloth beam, warp tension, and fabric geometry, yet comprehensive theoretical and practical models remain scarce. By examining the forces, motion patterns, and constraints associated with selvedge extraction, this research seeks to establish a detailed framework for forecasting fabric behavior during winding. Such an investigation not only aids in the design of more efficient weaving looms but also supports the development of predictive maintenance approaches and quality assurance practices in textile manufacturing.

2 Analysis of the fabric selvedge withdrawal process

The analysis shows that a weaving loom operates with two mechanical systems involving threads. The first system consists of the warp threads together with the fabric and the rigid elements interacting with them. This system includes the deformable warp threads with the fabric, as well as a number of rigid elements from other loom mechanisms. During certain phases of the loom's operating cycle, the rigid elements of these mechanisms interact with the warp threads and fabric, influencing their stress-strain state.

For the analytical study of the mechanical system of warp threads and fabric in a weaving loom, it is necessary to formulate a system of differential equations describing the motion of the warp threads and fabric along individual sections of the warp path: the warp beam, the heddles, the section "heddles – warp observer," "warp observer – harness," "harness – fabric selvedge," "fabric selvedge – breastbeam," "breastbeam – cloth beam," and "cloth beam – take-up roll." The equations should describe both the behavior of the threads and fabric in a free state and their interaction under conditions of frictional contact with the rigid elements of the mechanism. The overall system must include the differential equations of motion for the rigid elements that interact with the warp threads and fabric. Additionally, the system of equations should contain the coupling conditions for individual sections of the threads and fabric, as well as the equations governing contact with the rigid elements [1].

Solving the differential equations of the loom's elastic system under given initial and boundary conditions—both during acceleration and steady-state cycles—allows determination of the threads' and fabric's state. Equations for rigid elements not interacting with the warp or fabric during the cycle are excluded.

This task is highly complex; therefore, it is reasonable to focus on the following specific problems within the study:

1. Analysis of the effect of the heddle motion on the tension of the warp threads and on the withdrawal of the fabric selvedge by the cloth beam from the working zone.
2. Investigation of the impact of shed formation on warp thread tension and on the selvedge withdrawal process by the cloth beam.

3. Assessment of the influence of the weft beating-up process on the warp thread tension and on the selvedge withdrawal by the cloth beam.
4. Analysis of the stress-strain state in the breastbeam zone (from the fabric selvedge to the cloth beam).

To solve the stated problems, it is necessary to develop mathematical models of the threads and fabric [2]. When modeling a rigid thread, the following constraints and simplifying assumptions are adopted:

-A geometric restriction that takes into account the spatial arrangement of the thread.

-Assumption that the material is uniform and continuous throughout the length of the thread.

-Initial simplification: the thread structure is modeled as a two-dimensional (planar) system.

-Material model: the thread is assumed to behave as a linearly elastic and isotropic material (with viscoelastic effects incorporated if required).

-Stress–strain relationships: in the case of complex loading conditions in both the thread and the fabric, the correlations between stress and strain magnitudes are formulated for stretching, bending, and torsional deformation of a thread with finite length.

3 Derivation of Equivalent Equations of Statics, Kinematics and Dynamics

We assume a model of an ideally flexible thread, where $\bar{P} \neq 0$ represents the tension directed tangentially along the thread axis. The transverse force Q = 0 acts in the plane of the varying cross-section of the thread. $\overline{\mathrm{M}_B} = 0$ and $\overline{\mathrm{M}_T} = 0$ represent the bending and twisting moments, respectively. The equilibrium and motion of the fabric are considered in the form of a cylindrical surface with two flat-parallel edges that define the fabric width.

The adopted kinematic and force constraints make it possible to consider a particular simplified form of fabric motion, in which its surface, in a stressed-deformed state, takes the shape of a cylinder with two flat-parallel edges defining the fabric width. In this case, the stress-strain state is identical across all sections of the fabric strip that are perpendicular to the generatrix of the cylindrical surface [3].

Each elementary strip of fabric is conventionally defined along its entire length by two systems of cross-sections, perpendicular to the generatrix and separated by a small distance. Such a strip is considered as a thread, rigidly deformable under tension and bending by the action of a planar system of external forces, and having a flat configuration in the stressed-deformed state.

As a result, the differential equations of statics, kinematics, and dynamics for an element of a flat thread rigidly deformable under tension and bending coincide with the equations for an elementary section of the cylindrical fabric surface, rigidly deformable under similar conditions.

It is assumed that all fabric parameters remain unchanged along the width, which eliminates the need to consider the fabric state with respect to the width coordinate. This makes it possible, in the general case, to formally reduce two-dimensional problems related to the fabric to a one-dimensional problem along the length of the cylindrical cloth, analogous to a one-dimensional problem for a flat thread. Based on this approach, the process of fabric selvedge withdrawal by the cloth beam from the working zone can be regarded as the withdrawal of a flat thread from the working zone [4].

4 Analysis of the fabric selvedge withdrawal process from the working zone

To study the process of fabric selvedge withdrawal by the cloth beam from the working zone, the equilibrium of the fabric outside the beam surface is considered [5]. The analysis is carried out under conditions of steady motion of the elastic fabric, taking into account preliminary displacement and elastic interaction between the fabric and the beam. In this case, the fabric's contact with the beam surface is incomplete, since the beam surface is covered with a rough material that prevents continuous contact. Under such conditions, the fabric equilibrium can be described with consideration of partial frictional force on the rough surface, which makes it possible to accurately model the withdrawal process and assess its mechanical characteristics.

To solve the problem of fabric equilibrium on a rough surface with partial friction force, the following model is adopted. Let the withdrawn fabric segment *AB* lie on the surface of a cloth beam with radius *r* along a wrap angle *θ*. Forces $\overline{T_0}$ and $\overline{T_1}$ are applied to the fabric ends, gradually increasing from zero to prescribed values. The fabric is considered elastic, with the stress–strain relationship given as ($t = 1 + \lambda T$). The contact between the fabric and the beam is also assumed to have only elastic properties, characterized by the parameter $|T_0| = a|ʒ|$, where a=const.

After applying forces to the fabric ends, all its points undergo a displacement ʒ. The initial displacement at point *A* is denoted as $ʒ_0$. Let a point of the fabric located at position C_0 in the withdrawn state move to position *C'*. The coordinate origins *S* and S_0 are taken at point *A*. Then the following relation holds:

$$ʒ = ʒ_0 + S \cdot S_0$$

In Eulerian coordinates this expression takes the form:

$$ʒ = ʒ_0 + S - S_0\,(S')$$

Differentiating the last relation, we obtain:

$$\frac{dʒ}{dS} = 1 - \frac{1}{f} = \frac{\lambda T}{1+\lambda T}$$

Suppose that no forces act on the fabric other than the normal reaction of the surface and the friction force [6]. In this case, the equilibrium of the fabric is described by the following system of differential equations:

$$T_a = -\,aʒ$$

$$\frac{1+\lambda T}{M_0}\frac{dT}{dS} = -\,F_1 = -\,T_a$$

$$\frac{1+\lambda T}{M_0 r}\,T = -\,F_2 = N_1\frac{dʒ}{dS} = \frac{\lambda T}{1+\lambda T}$$

Where *T* - is the fabric tension force;

F_1 and F_2 - are the forces applied to the ends of the fabric;

N_1 - is the normal reaction of the surface;

a - is the contact stiffness coefficient.

For simplicity, it is assumed that the fabric is slightly stretchable ($\lambda T<1$). The equilibrium equation for such a fabric has the following form:

$$\frac{1}{M_0}\frac{dT}{dS} = -T_a = a\mathfrak{z} \qquad (1)$$

$$\frac{T}{M_0 r}=N \qquad (2)$$

$$\frac{d\mathfrak{z}}{dS} = \lambda T \qquad (3)$$

From equalities (1) and (3), we obtain:

$$\frac{d^2T}{dS^2} - a\alpha M_0 = 0 \qquad (4)$$

The solution of this equation has the form:

$$T = C_1\, Ch\,(\sqrt{a\alpha\mu_0 S}) + C_2\, Sh\,(\sqrt{a\alpha\mu_1 S}$$

The product of the constants C_1 and C_2 is determined from the boundary conditions:

$T = T_0$ at $S = -\mathfrak{z}$,

$T = T_1$ at $S = r\theta - \mathfrak{z}_0$

After determining the constants C_1 and C_2 and transforming using the value $\mathfrak{z}_0$, we obtain the following law for the distribution of tension along the length of the fabric:

$$T = T_0\, Ch\,(\sqrt{a\alpha\mu_0 S}) + \frac{T_1 - T_2 Ch(\sqrt{a\alpha\mu_0}\, r\theta}{Ch(\sqrt{a\alpha\mu_0}\, r\theta}\, Sh\,(\sqrt{a\alpha\mu_1 S}$$

or

$$T = \frac{T_0 Sh[\sqrt{a\alpha\mu_0}(r\theta - S)] + T_1 Sh(\sqrt{a\alpha\mu_0} S}{Sh(\sqrt{a\alpha\mu_0} r\theta} \qquad (5)$$

The fabric can remain in equilibrium without slipping only as long as, at all points, the fullness coefficient $|\lambda| < 1$. Let us determine the points where $|\lambda|$reaches unity, beyond which an increase in the difference $T_1 - T_2$ will cause the fabric to slip. The fullness coefficient is given by [7]:

$$\lambda = \frac{T_a}{KN}$$

By substituting the values of T_a and N from equations (1) and (2), we determine the value of λ and its derivative $\frac{d\lambda}{dS}$, which take the following form:

$$\lambda' = \frac{r}{K}\, a\alpha\mu_0\, \frac{T_0^2 - T_1^2 - 2T_0T_1 Ch(\sqrt{a\alpha\mu_0} r\theta)}{[T_0 Sh[\sqrt{a\alpha\mu_0}(r\theta - S)] + T_1 Sh(\sqrt{a\alpha\mu_0} S]^2} \qquad (6)$$

From the resulting expression, it is evident that the product λ' cannot change along the take-up arc, i.e., $\lambda\,(S)$ is a monotonic function [8].

In this case, the maximum value $|\lambda|_{Max}$ can occur only at one of the boundary points of the wrap arc:

If $\lambda' > 0$, then $\lambda\,(S)$ increases with increasing S, i.e., at

$$Ch(\sqrt{a\alpha\mu_0} r\theta) < \frac{T_0^2 + T_1^2}{2T_0T_1} \qquad (7)$$

$\lambda\,(S)$ decreases if:

$$Ch(\sqrt{a\alpha\mu_0} r\theta) > \frac{T_0^2 + T_1^2}{2T_0T_1} \qquad (8)$$

Let us determine the condition under which the fullness coefficient reaches $|\lambda|= 1$ at point *a*, meaning that fabric slipping initially occurs at this point. At the same time, $|\lambda_a| > |\lambda_c|$ i.e., condition (7) is satisfied, and $\lambda_a < 0$. In this case:

$$|\lambda_a| = -\lambda_a = -\frac{r}{K}\sqrt{a\alpha\mu_0}\frac{T_0 Ch(\sqrt{a\alpha\mu_0} r\theta) - T_1}{T_0 Sh(\sqrt{a\alpha\mu_0} r\theta)} = 1$$

Determining T_1/T_0 from the last equality and substituting it into (7), we obtain the desired condition for the fabric to slip from the roll surface at point *a*.

$$K^2 > r^2 a\alpha\mu_0 \quad (9)$$

Similarly, it can be stated that the fabric will slip on the roll surface if the following conditions are satisfied:

$$K^2 < r^2 a\alpha\mu_0 \quad (10)$$

It should be noted that when the difference $T_1 - T_2$ increases, fabric slipping initially occurs not along the entire length, but only in a certain zone adjacent to the boundaries at points *A* or *B*. With a further increase in $T_1 - T_2$, this zone expands, and a corresponding amount of relative displacement is observed along the contact arc [9].

From the resulting expression (9), it is evident that the state of the fabric on the roll surface is proportional to the square of the roll radius, the linear density of the warp threads, the stretchability coefficient of the warp threads, and the main feed coefficient [10].

Let us consider a point on the roll surface where fabric slipping may occur for the given production parameters: $r=0{,}08м$, $\mu_0 = N=36$, $\alpha=0{,}01$, $a=1$, $K=0{,}3$. Substituting these values into formula (3), we obtain [11]:

0,09> 0,0023

From the resulting expression, it follows that when processing fabric with the specified parameters on the STB-180 loom, fabric slipping from the roll surface will occur at point *A*.

5 Conclusion

A mathematical model describing the pulling of the fabric selvedge from a roll has been developed. The equilibrium differential equation was derived and solved, and the slipping conditions at different points were identified. It was found that slipping is directly proportional to the square of the roll radius, the linear density and elasticity of the warp threads, and the main feed coefficient.

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