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General aspects regarding the kinematic and dynamic analysis of the fabric take up/ cloth roller

Cristian Matran[1,*], and *Nicolae* Bercan[1]

[1]Lucian Blaga University of Sibiu, Faculty of Engineering, Machines and Industrial Equipments Department, 550012 Sibiu, Romania

Abstract. The aim of this paper is to presents different aspects regarding the kinematic and dynamic behaviour of the fabric winding at the weaving loom. In this paper shall be presented the kinematic diagram for operating the cloth roll on the weaving machine, making the study of kinematic and dynamic cloth behaviour, setting up the expression of fabric tension. Finally, where drawn the charts of the variation of the fabric load depending by kinematic and constructive parameters.

1 Introduction

In present days, the request for the high quality garments imposes certain trends in the weaving loom development/construction. The modern weaving loom uses positive take-up mechanisms, acted by individual c.c. motors and clutches, protecting the fabric for over loading.

The paper presents a kinematical and a dynamical analysis of the take-up and cloth roller mechanism. The command schema and the kinematic chain that acting the take up cylinder contain the computer, gears, chain and frictional clutch as is shown in Figure 1 [1-2], where: 1 – loading cell, 2 – computer, 3 – d. c. motor, 4 - z_i gears, 5 – cloth take up roller, 6 – chain and chain wheels, 7 – clutch, 8 – cloth roller.

2 Theoretical kinematical and dynamical aspects of the fabric loading

In the fabric take up and rolling process, the fabric element is extracted with a constant velocity. The characteristics of the cloth (from the paper's point of view) are:
- specific weight "ρ";
- fabric thickness "δ";
- the length of the cloth roller "l_0";
- the diameter of the fabric roller "d_0";
- the axial moment of inertia "J_0".

* Corresponding author: cristian.matran@ulbsibiu.ro

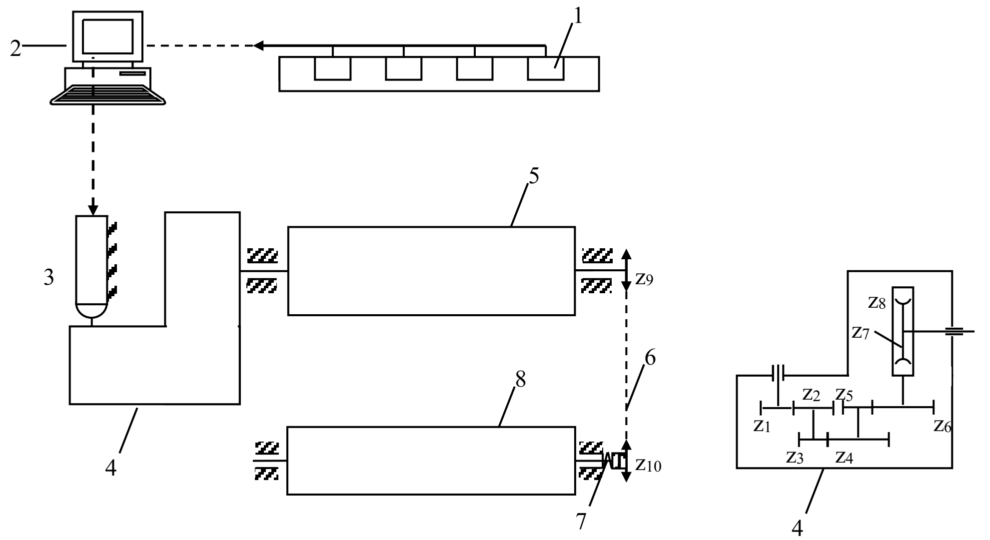

Fig. 1. The command schema of the take up and the fabric rolling mechanism (1- loading cell, 2- computer, 3- d. c. motor, 4- z_i gears, 5- cloth take up roller, 6- chain and chain wheels, 7- clutch, 8- cloth roller).

In the process of the rolling cloth, its axial momentum of inertia (J_Δ) represents a sum of the both empty fabric roller and fabrics' axial momentum of inertia (1) [3-4].

$$J_\Delta = J_0 + J_\Delta^{tes} \tag{1}$$

The axial moment of inertia of the empty fabric roller (J_0) could be calculated using:

$$J_{cil} = J_{cil}^{plin} - J_{cil}^{gol} = \frac{m_{cil}^{plin} \cdot r_0^2}{2} - \frac{m_{cil}^{gol} \cdot r_{\text{int}}^2}{2} \tag{2}$$

Where: m_{cil}^{plin}, m_{cil}^{gol} – the mass of the filled/empty fabric roller, [kg], r_0, r_{int} – external/internal radius of the fabric roller, [m].

Using the constructive particularities of the beam and the density of its material (aluminium), the equation (2) became:

$$J_{cil} = \frac{\pi \cdot \rho \cdot h}{2}\left(r_0^4 - r_{\text{int}}^4\right) \tag{3}$$

Where: ρ – Aluminium density [2700 kg/m^3], h – Length of the fabric beam [m], r_0, r_{int} – external/internal radius of the fabric beam, [m].

The fabrics' axial momentum of inertia , J_Δ^{tes} depends by time (indirectly) and could be calculate using the relation:

$$J_\Delta^{tes} = \int r^2 dm \tag{4}$$

Where: r_0 – the radius of the empty fabric beam, [m], R – maximal radius of the fabric roller, [m], r – the radius of the fabric roller at a specific time, [m], dm – elementary mass, [kg].

And

$$dm = \rho \cdot dV \tag{5}$$

dV – elementary volume, Figure 2.
It results:

$$dm = \rho \cdot dV = \rho \cdot dl \cdot dA = \rho \cdot dl \cdot dl_1 \cdot dr = \rho \cdot dl \cdot r \cdot d\theta \cdot dr \tag{6}$$

for $dl \in [0, l_0]; d\theta \in [0, 2\pi]; dr \in [r_0, r]$
Where *dl* – elementary length of cloth roller.

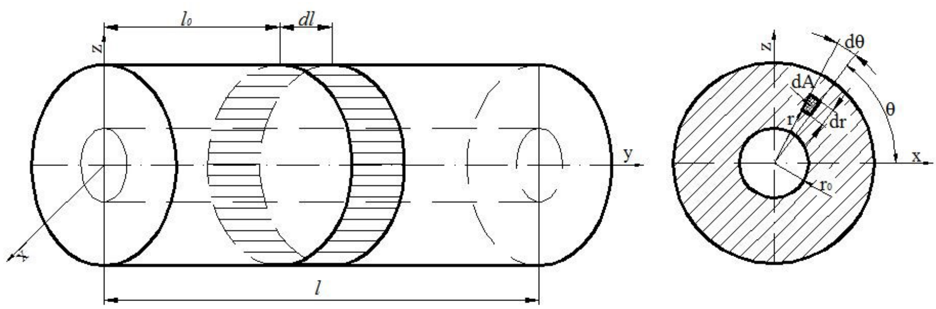

Fig. 2. The elementary volume calculus, dV.

dA –surface element;
dθ –; the elementary angle;
$dl_1 = r \cdot d\theta$
dl_1 – elementary length of the circles' arch.
Replacing (6) in (4), it results:

$$J_{\Delta}^{tes} = \rho \cdot \int_{r_0}^{R} r^3 dr \cdot \int_0^l dl \int_0^{2\pi} d\theta \tag{7}$$

Where

$$r = r_0 + n \cdot \delta \qquad n = \frac{\theta}{2\pi} \tag{8}$$

n –the number of cloth layers at a specific moment.
Finally, will obtain:

$$J_{\Delta}^{tes} = \frac{\pi \rho l}{2}\left[\left(r_0 + \delta \cdot \frac{\theta}{2\pi}\right)^4 - r_0^4\right] \tag{8}$$

θ – the warping angle, [rad];
δ – fabrics' thickness, [m].

The elements of the fabric winding are show in the figure 3.

The theorem of the kinetic moment variation, calculated in relation with the rotation axis of the fabric beam, is given by:

$$\dot{K}_\Delta = M_\Delta \tag{9}$$

Where

$$K_\Delta = J_\Delta \cdot \omega \tag{10}$$

$$\dot{K}_\Delta = \dot{J}_\Delta \cdot \omega + J_\Delta \cdot \dot{\omega} \tag{11}$$

$$M_\Delta = M_a - T \cdot r \tag{12}$$

It results:

$$\dot{J}_\Delta \cdot \omega + J_\Delta \cdot \varepsilon = -T \cdot r + M_a \tag{13}$$

Where M_a –drive momentum, [N·m],

$$M_a = 9.55 \cdot 10^3 \frac{P}{n_s} \tag{14}$$

P –the power of the driving motor [W];
n_s –speed of the fabric roller [rpm].

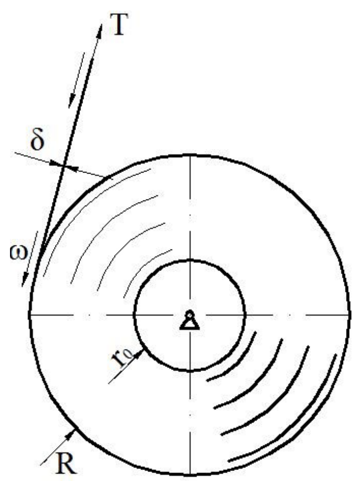

Fig. 3. Elements of the fabric winding [5].

From the equation (13), we can determine the fabric tension:

$$T = \frac{1}{r} \cdot \left(M_a - \dot{J}_\Delta \cdot \omega - J_\Delta \cdot \varepsilon \right) \tag{15}$$

Where: ε –angular acceleration, [rad/s^2].
Deriving the equation (1), we get:

$$\dot{J}_\Delta = \dot{J}_0 + \dot{J}_\Delta^{tes} \tag{16}$$

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And

$$\dot{J}_0 = 0 \tag{17}$$

Deriving and successive processing the equation (8), we get:

$$\dot{J}_{\Delta}^{tes} = \frac{4\pi\rho l}{2}\left(r_0 + \frac{\delta \cdot \theta}{2\pi}\right)^3 \cdot \frac{\delta \cdot \dot{\theta}}{2\pi} = \rho \cdot l \cdot \delta \cdot r^2 \cdot v_T \tag{18}$$

From figure 3 results the angular acceleration deriving the (9) in relation to time:

$$\varepsilon = \dot{\omega} = \frac{d\omega}{dt} \tag{19}$$

Realizing a change of variable in (19), we'll obtain:

$$\varepsilon = \frac{d\omega}{dr} \cdot \frac{dr}{dt} \tag{20}$$

Where:

$$\frac{d\omega}{dr} = \frac{d}{dr}\left(\frac{v_t}{r}\right) = -\frac{v_t}{r^2} \tag{21}$$

$$\frac{dr}{dt} = 0 + \delta \cdot \dot{n} = \delta \cdot \left(\frac{\dot{\theta}}{2\pi}\right) = \frac{\delta}{2\pi} \cdot \dot{\theta} = \frac{\delta}{2\pi} \cdot \left(\dot{\omega} \cdot t\right) = \frac{\delta \cdot \omega}{2\pi} = \frac{\delta \cdot v_t}{2\pi \cdot r} \tag{22}$$

Replacing in (20), it became:

$$\varepsilon = -\frac{v_t}{r^2} \cdot \frac{\delta \cdot v_t}{2\pi \cdot r} = -\frac{\delta \cdot v_t^2}{2\pi \cdot r^3} \tag{23}$$

Replacing the calculated sized in relation (15), the final relation will be:

$$T = \frac{1}{r}\left[M_a - \rho \cdot l \cdot a \cdot r^2 \frac{v_t^2}{r} + \frac{\delta \cdot v_t^2}{2\pi \cdot r^3} \cdot \frac{\pi \cdot \rho \cdot l}{2}\left(r^4 - r_{\text{int}}^4\right)\right] \tag{24}$$

3 Experimental aspects to calculate fabric loading

The theoretical values were applied to the Somet Thema weaving loom, with the main parameters shown in table 1.

The working parameters of the loom being optimized by the loom's computer, the transmission of the movement to the fabric roller presents different technological capabilities:

- z_1=48/**24**/17, z_2=80/**96**/103, z_3=16, z_4=48, z_5=16, z_6=48, z_7=2, z_8=90, z_9=45, z_{10}=31;
- main motor speed, max. 2350 rpm.;
- take up roller speed, 100 – 1400 rpm;
- pick density, 5 - 150 picks/cm.

Table 1. Combination of gears to calculate maximal fabric density.

Type	Z	yarns/cm	yarns/inch	Comment
B	$z_1 = 40$	5 – 40	12,7 – 101,6	At request
	$z_2 = 80$			
C	$z_1 = 24$	10 – 80	25,4 – 203,2	Standard
	$z_2 = 96$			
D	$z_1 = 17$	15 - 150	38,1 - 381	At request
	$z_2 = 103$			

Appling the specific parameters of the loom in equation (27) it results the values of the fabric loading as shown in table 2.

Table 2. Fabric loading.

n_{et} [rpm]	Ma [Nm]	δ [m]	J_0 [kg·m²]	ρ_s [kg/m²]	l_0 [m]	r_0 [m]	r [m]	T [N]
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1000	3555.8509
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1125	3160.7564
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1250	2844.6808
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1375	2586.0735
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1500	2370.5673
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1625	2188.2160
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1750	2031.9149
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.1875	1896.4539
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2000	1777.9255
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2125	1673.3417
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2250	1580.3782
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2375	1497.2004
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2500	1422.3404
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2625	1354.6099
470	355.5851	0.00429	0.18881	0.1414	1.9	0.1	0.2750	1293.0367

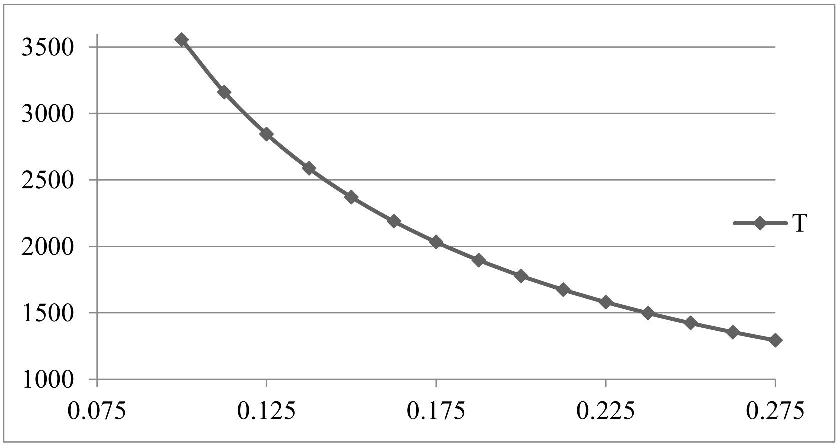

Fig. 4. The variation of the fabric loading depending by winding radius.

4 The Clutch's influence

As is seen in the weaving process, the fabric load is falling down according with the rising of the radius, as shown in table 4 and figure 4.

On the other hand, using the gear ratio between take up roller and the cloth beam, the peripheral speed of the fabric roller is rising, overloading the fabric (the gear ratio is greater than 1). This overload of fabric could be lowered using a frictional clutch. Because the same element of fabric extracted by the take up roller must be wrapped on the cloth roller, and keeping in mind that the both peripheral speeds of the rollers are different, we could calculate the clutch's slippage.

Starting from the equation of the rollers' peripheral velocity depending by its speed, we obtained:

$$l_t = l_s \tag{25}$$

Where:
$l_{t,s}$ – the length of a fabric element, [m];

On the other hand, the expression of the cloth roller's speed, based on the take up roller's speed becomes:

$$n_s = n_t \cdot \frac{z_9}{z_{10}} \cdot \frac{100 - a}{100} \tag{28}$$

Where:
z_9, z_{10} – sprockets' size;
a – clutch slippage, [%].

$$n_s = \frac{v_t}{2 \cdot \pi \cdot r_x} = n_t \cdot \frac{z_9}{z_{10}} \cdot \frac{100 - a}{100} \tag{29}$$

Where:
v_t – peripheral speed of the take up roller, [m/s];
r_x – the radius of the cloth roller at a specific time, [m].
According with (29), we can calculate the radius of cloth roller:

$$r_x = \frac{100 \cdot v_t}{2 \cdot \pi \cdot (100 - a)} \cdot \frac{z_{10}}{z_9} \tag{30}$$

The slippage of the clutch will result according with (30):

$$a = 100 - \frac{100 \cdot v_t}{2 \cdot \pi \cdot n_t \cdot r_x} \cdot \frac{z_{10}}{z_9} \tag{31}$$

Considering that a=0% (the working moment of clutch), the cloth roller's radius is:

$$r_x = \frac{v_t}{2 \cdot \pi \cdot n_t} \cdot \frac{z_{10}}{z_9} \tag{32}$$

At limit, when $r_x \to \infty$,

$$a = 100 \tag{33}$$

Table 3. Clutch's slippage.

n_{et} [rpm]	n_t [rpm]	v_t [m/s]	r [m]	a [%]
470	0.29	0.255	0.1000	3.5923
470	0.29	0.255	0.1125	14.3043
470	0.29	0.255	0.1250	22.8738
470	0.29	0.255	0.1375	29.8853
470	0.29	0.255	0.1500	35.7282
470	0.29	0.255	0.1625	40.6722
470	0.29	0.255	0.1750	44.9099
470	0.29	0.255	0.1875	48.5825
470	0.29	0.255	0.2000	51.7961
470	0.29	0.255	0.2125	54.6316
470	0.29	0.255	0.2250	57.1521
470	0.29	0.255	0.2375	59.4073
470	0.29	0.255	0.2500	61.4369
470	0.29	0.255	0.2625	63.2732
470	0.29	0.255	0.2750	64.9426

Based on the Table 3, the graphical variation of the slippage is presented in figure 5.

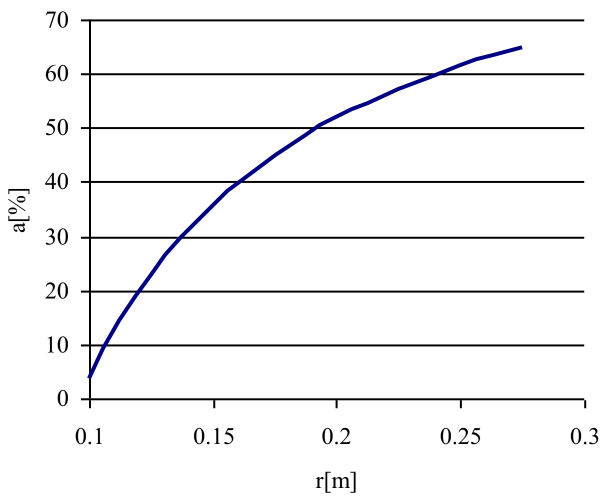

Fig. 5. The clutch's slippage.

5 Conclusions

Starting from kinematical and dynamical analysis, it results a calculus formula of the fabric loading in the wrapping process, depending by the geometrical dimensions of the cloth roller.

Also, we obtained the mathematical equation and diagrams of speed variation and clutch's slip, depending by the radius of the cloth roller, too.

As is seen in the weaving process, the fabric load is falling down according with the rising of the radius, as shown in table 2 and figure 4.

On the other hand, using the gear ratio between take up roller and the cloth beam, the peripheral speed of the fabric roller is rising, overloading the fabric. This overload of fabric could be eliminated by the worker by using a clutch (raising the slippage of the clutch's discs).

The worker's action in the fabric rolling is more often with the radius raising and it decrease the number of weaving loom surveyed by a worker.

The state-of-the-art weaving looms use an electronic controlled take up and individual motors [6-7].

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