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Technological Calculation Relations for Computer Control of the Revolutions of the Driving Motors of a Band Warping Cylindrical Drum

Abstract
Band warping machines with separate variable speeds, one for rotation and the other for the axial advance of the warping cylindrical drum, can achieve the self-regulation of these motors speeds through computer programs based on mathematical relations. This paper presents calculus equations for the kinetic feed of a warping cylinder, the rotative speed of the feed engine, depending upon the warp characteristics, for the rolled strip length and for the number of winding rotative speeds. The equations can be used in computer programs for textile windings that are not recommended or cannot be realised on line measuring for the winding ray.

Key words: *band warping machines, computer control, technological relations.*

Introduction

In modern strip warping machines, driving of the warping cylinder is realised by using two computer controlled engines with a variable rotative speed [1]. Engine M_1 spins the warping cylinder, while engine M_2 drives the mechanism for the axial feeding of the warping cylinder, as shown in ***Figure 1***.

For the equation between the warping cylinder's rotative speed, depending on the warp speed, and the winding ray, respectively, the rotative speed mechanical variators used for the variation in this rotative speed is known [2, 3]. The present paper extends the equation of the warping cylinder's rotative speed by including in it warp characteristics, the rolled-up length of the warp and the number of winding rotations. The equations presented allow the elaboration of computer programs for textile windings that are not recommended or cannot be realised – line measuring for the winding ray and its utilisation as a computer input data variable.

The equations for calculating the axial feed of the sheets (lays patches) for one rotation of the warping cylinder depending on the warp characteristics are also known [2 - 6]. They are useful for the choice of kinematic advance of the feeding mechanic variators driven by the warping cylinder.

This paper presents calculus equations for the kinetic feed of a warping cylinder, for the feed engine's rotative speed, depending upon the warp characteristics, for the rolled strip length and the number of winding rotative speeds. The equations can be used in computer programs for the feeding engine's rotative speed, correlated with the rotative speed of the warping cylinder's rotative engine.

The speeds of motors M1 and M2 are controlled by computer 6 of the band wrapping machine. This paper presents relations for calculation of the two engines' speeds according to the characteristics and technological parameters of the warping.

Relations for calculating the speed of the electromotor of a band warping cylindrical drum

Kinematically, the speed of the electromotor cylindrical drum is:

$$n_{mt} = n_{tx}\, i_{tm} \qquad (1)$$

where:

n_{mt} - speed of the electromotor of the band warping cylindrical drum;

n_{tx} - speed of the band warping cylindrical drum;

i_{tm} - transmission report between the axle of the cylindrical drum and that of the driving motor.

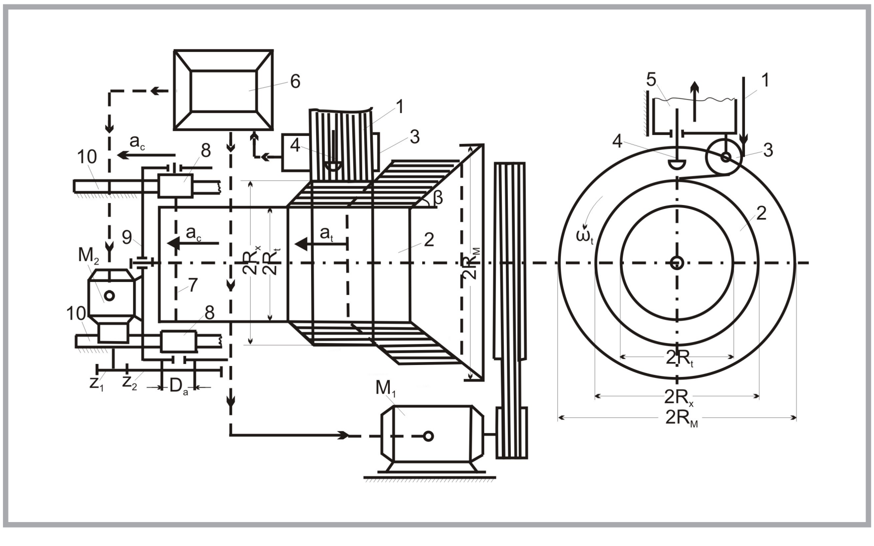

***Figure 1**. Scheme of band wrapping and of the cylindrical drum setting at work; 1- wrapping band, 2- band wrapping the cylindrical drum, 3- length measuring the cylinder, 4- measuring sensor for layer thickness, 5- support for the measuring cylinder, 6- computer of the warping machine, 7- axle for the cylindrical drum advance, 8-feed weel, 9- cylindrical drum truck, 10- rails for advance, M_1- motor for the rotation of the cylindrical drum, and M_2- motor for the advance of the cylindrical drum.*

The speed of the cylindrical drum depends on the speed of warping v and on the radius of wrapping, R_x, according to the classical relation:

$$v = 2 \pi R_x n_{tx} \quad (2)$$

where:
- v - linear speed of the band warping;
- R_x - warping radius at a given moment;
- n_{tx} - speed of the band warping cylindrical drum, corresponding to radius R_x.

The wrapping radius can be calculated with the relation:

$$R_x = R_t + \delta N_x \quad (3)$$

where:
- R_t - radius of the empty wrapping cylindrical drum;
- δ - thickness of a layer;
- N_x - number of rotations made by the band wrapping cylindrical drum from the beginning of the band until the wrapping radius R_x is reached.

The thickness of a layer is calculated with the relation:

$$\delta = T_t P_u/\rho \times 10^{-5} \quad (4)$$

where:
- T_t - linear density of the yarn, in tex;
- δ - thickness of a layer, in cm;
- P_u - thickness of yarns in the band, in yarns/cm;
- ρ - wrapping density, in g/cm^3 [1, 2].

The results from here give the possibility of calculating the ray R_x, in cm, with the relation:

$$R_x = R_t + T_t P_u N_x/\rho \times 10^{-5} \quad (5)$$

The introduction of this relation into the computer program for controlling the band wrapping speed of the cylindrical drum requires on-line recording of the number of rotations of the wrapping N_x. Concurrently, the length L_x wrapped on the cylindrical drum from the beginning of the band until a certain value of R_x is reached is determined and transmitted to the computer. The relation between the length L_x and range R_x can be expressed by the relations:

$$L_x = \frac{\pi\left(R_x^2 - R_t^2\right)}{\delta}, \text{ respectively} \quad (6)$$

$$R_x = \sqrt{R_t^2 + \frac{T_t P_u}{10^5 \pi \rho} L_x}$$

According to the parameter measured on–line on the machine, N_x or L_x, the speed of the band warping cylindrical drum required can be determined with one of the following relations:

$$n_{tx} = \frac{v}{2\pi\left(R_t + \frac{T_t P_u}{10^5 \rho} N_x\right)} \quad (7)$$

or

$$n_{tx} = \frac{v}{2\pi\sqrt{R_t^2 + \frac{T_t P_u}{10^5 \pi \rho} L_x}} \quad (8)$$

Under such conditions, the computer will be able to control the speed of the spinning motor of the band warping cylindrical drum using a program based on one of the following relations:

$$n_{mt} = \frac{v i_{mt}}{2\pi\left(R_t + \frac{T_t P_u}{10^5 \rho} N_x\right)} \quad (9)$$

or

$$n_{mt} = \frac{v i_{mt}}{2\pi\sqrt{R_t^2 + \frac{T_t P_u}{10^5 \pi \rho} L_x}} \quad (10)$$

Relations for calculating the speed of the feed electromotor of the band warping cylindrical drum

Kinematically, based on the scheme plotted in ***Figure 1***, the speed of the advance of the warping cylindrical drum is calculated with the relation:

$$v_{ac} = n_{ma}\, i_{ma}\, \pi\, D_a \quad (11)$$

where:
- v_{ac} - the advance speed of the warping cylindrical drum, kinematically attained;
- n_{ma} - speed of the feed motor;
- i_{ma} - report of transmission between the axle of the feed motor and the advance axle;
- D_a - diameter of the feed wheel.

The axial kinematic advance of the cylindrical drum, corresponding to one of its rotations, can be determined with the relation:

$$a_c = v_{ac}/n_{tx} \quad (12)$$

where a_c is the kinematic advance that should be achieved in a cylindrical drum rotation (wrapping of a layer).

Based on relations (7) and (8), calculation of the kinematic advance of the warping cylindrical drum with one of the following relations becomes possible:

$$a_c = \frac{2\pi^2 n_{ma}\, i_{ma} D_a \left(R_t + \frac{T_t P_u}{10^5 \rho} N_x\right)}{v} \quad (13)$$

$$a_c = \frac{2\pi^2 n_{ma}\, i_{ma} D_a \sqrt{R_t^2 + \frac{T_t P_u}{10^5 \pi \rho} L_x}}{v} \quad (14)$$

The technological advance a_t necessary for the achievement of some cylindrical layers is calculated with the relation:

$$a_t = \frac{T_t P_u}{10^5 \rho g \beta} \quad (15)$$

where:
- a_t - the technological advance necessary for a certain warping, in cm/rotations;
- β - conical shape of the cylindrical drum [2, 4].

To achieve the wrapping of bands in cylindrical layers and correct arrangement of the first band on the cone, the kinematic advance should be equal to the technological advance:

$$a_c = a_t \quad (16)$$

From relation (16) we obtain the possibility of calculating the speed of the feed motor with one of the formulas below:

$$n_{ma} = \frac{v T_t P_u}{2 \times 10^5 i_{ma} \pi^2 D_a \rho tg\beta \left(R_t + \frac{T_t P_u}{10^5 \rho} N_x\right)} \quad (17)$$

$$n_{ma} = \frac{v T_t P_u}{2 \times 10^5 i_{ma} \pi^2 D_a \rho tg\beta \sqrt{R_t^2 + \frac{T_t P_u}{10^5 \pi \rho} L_x}} \quad (18)$$

The on-line measured parameter transmitted to the machine's computer i.e. N_x or L_x will determine and then command the speed of the feed motor, using a program based on relations (17) or (18).

Experimental studies on the speed variation of the electromotor of a band warping cylindrical drum

To exemplify the use of the above relations, the realisation of warpings from wool – type yarns on a warping machine in Benninger Ben-tronic bands was taken as a case study. The fixed constructive elements necessary for the programs, based on relations (10) and (18), are:
$R_t = 50$ cm; $i_{tm} = 12.5$; $\beta = 11°$;
$D_a = 15$ cm; $i_{ma} = 0.0075$.

According to the characteristics of warping, concrete values for the fineness and thickness of yarns (T_t and P_u) are known. The warping speed is established, from case t case, according to the quality of yarns, while the density of wrapping ρ depends on the nature and tension of the yarns. These approximate densities are used by the computer program of the Benninger Ben-tronic machine as data bases, coded ST 01… ST 13. The values of this data base for wool type yarns are listed in ***Table 1*** [1].

The command to reduce the number of revolutions of the two feed motors of the cylindrical drum, according to L_x, requires knowledge of the effective density of band wrapping, ρ_e'. The effective density can be determined by the warping machine computer with the relation:

$$\rho_e = \frac{L_e T_t P_u}{10^3 \pi \left(R_e^2 - R_t^2\right)}$$

i.e. (19)

$$\rho_e = \frac{L_e T_t P_u}{10^3 \pi \left(2 R_t \Delta R_e + \Delta R_e^2\right)}$$

where:

Le - the effective length of the band wrapped on the warping cylindrical drum, in m;

ρ_e' - effective density, in g/cm ^{3};

R_e and R_t - effectively measured radius and that of the empty cylindrical drum, in cm;

ΔR_e - increase in the wrapping range, in cm, effectively measured as a result of the deposition of length L_e on the cylindrical drum; for the Benninger Ben–tronic machine the increase in the range is measured by sensor 4 (***Figure 1***);

P_u - thickness of the yarns during warping in yarns/cm;

Table 1. *Data base values.*

Yarn type	Tension, cN/dtex	Density ρ_0, g/dm^3	Variation, %	Compacting coefficient
Carded wool yarns	0.04	320	± 15	0.82
Wool and polyester blended yarns	0.08	500	± 15	0.85
Twisted worsted yarns	0.08	420	± 16	0.85

Table 2. *Densities during wrapping on the cylindrical drum*

Linear density, tex, and the type of yarn	ρ_0, g/cm^3	ρ_{eo}, g/cm^3	L_e, m	P_u, yarns/cm	ΔR_e, cm	ρ_e, g/cm^3
111.11 tex carded	0.32	0.213	780	10.48	11.7	0.221
95.24 tex × 2 carded	0.32	0.247	280	7.22	4.45	0.264
20.83 tex × 2 worsted	0.42	0.447	960	20.80	5.45	0.460

The Benninger machine, the value of the effective density ρ_{eo} is determined at the beginning of the first band, and thus the debsity ρ_0 from the data base is corrected. This effective density will be used by the machine's computer for all commands of self-regulation of the speeds of the two cylindrical drum motors.

When deploying bands, the tension of yarns can be modified, and consequently the effective density as well ρ_e occurred at the end of the bands. If the differences are significant, these can negatively affect the quality of band wrapping, generating destructive effects [7]. In ***Table 2***, some experimental data obtained during the warping of some wool type yarns on a Benninger Ben-tronic machine are presented. Significant differences may be observed between the effective densities ρ_e achieved at the end of the wrapping and the ρ_0 densities taken from the data base. Yarn tension adjusted during warping was beneath the values recommended in the data base to diminish yarn breakage, the effect of which was smaller densities. The effective densities ρ_{eo} automatically determined at the beginning of the first band by the computer program are similar to the experimental ρ_e values measured at the end of the bands. Smaller variations in density do not negatively affect the quality of wrapping.

Knowledge of the values of the effective densities ρ_e allows to trace the decrease curves of the two motors speeds for driving the warping cylindrical drum n_{mt}, as presented in ***Figure 2***, for n_{ma} - ***Figure 3***, according to length L_x of the wrapped band. The curves of the two figures are specific to the warpings achieved for yarns of carded wool of T_t = 111.11 tex and folded 20.83 tex × 2 yarns from combed wool.

The maximum length of the band L_M up to which warping can be programmed depends on the constructive characteristics of the warping cylindrical drum and on the warping characteristics, which can be calculated with the relation:

$$L_M = \frac{10^3 \pi \rho_e \left(R_M^2 - R_t^2\right)}{T_t P_u} \quad (20)$$

where:

L_M - the maximum length of wrapping on the cylindrical drum in m;

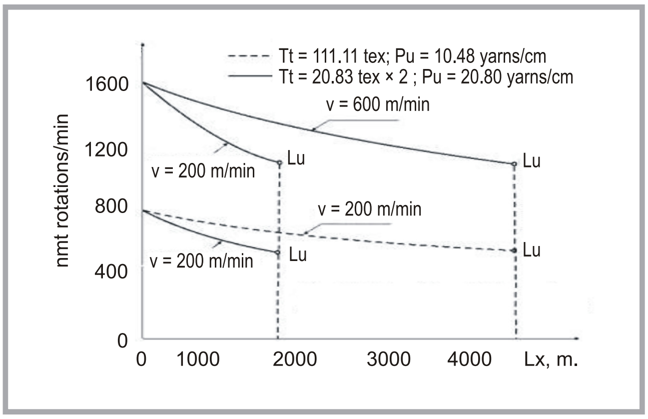

Figure 2. *Variation of the speed of the motors with the wrapped length*

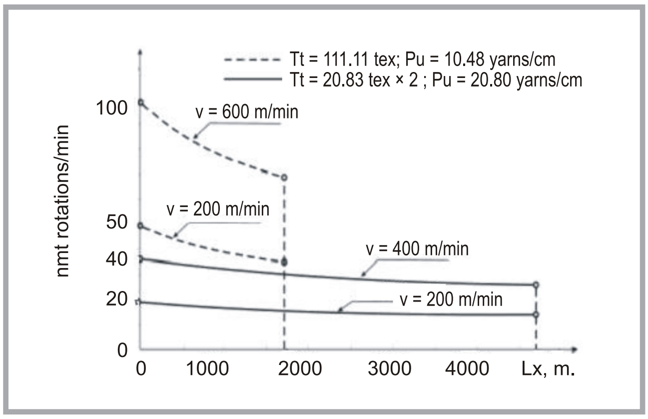

Figure 3. *Variation of the speed of the motors with the length L_x.*

ρ_e - effective density of wrapping on the warping cylindrical drum;
R_M - maximum wrapping radius which is possible to be achieved on the warping cylindrical drum in cm;
T_t - linear density of yarns in tex;
P_u - thickness of yarns in warping in yarns/cm.

The decrement curves of the motor speed of the warping cylindrical drum, according to length L_x, of the wrapped band (***Figure 2,*** see page 49) prove the following technological aspects:

- a decrease in the spinning motor speed is greatly influenced by the warping characteristics (T_t; P_u; ρ);
- the thicker and denser the warping yarns, the faster the decrease in the spinning motor speed is;
- the warping speed directly influences the speed of the spinning motor, no matter the warping characteristics.

All these technological conditions can be assured by the warping machine's computer, which uses a program based on the technological relations presented in this paper. Using a specific program, the computer will control the spinning motor speed n_{mt} according to the value L_x registered on the computer on the basis of curves similar to those plotted in ***Figure 2*** (see page 49). Small differences may be noticed to the extent to which ρ_{eo} is different from ρ_e, or the control for reducing the speed is given cyclically according to a certain wrapped length.

Figure 3 (see page 49) presents curves for decreasing the feed motor speed of the warping cylindrical drum, n_{ma} according to the length of the wrapped band L_x for two warpings with yarns of different thickness and density wrapped at two warping speeds. The curves in ***Figure 3*** (see page 49) emphasise the following technological requirements for the speed of the feed motor:

- at the same lengths wrapped on the warping cylindrical drum, the faster the warping speed, the faster the feed motor speed will be.
- at the same warping speed and wrapped length, the faster the feed motor speed, the thicker and denser the yarns in the warping band are;
- the decrease curves of the feed motor speed, depending on the length of the band wrapped on the cylindrical drum, differ as a function of the warping characteristics (T_t; P_u; ρ) and warping speed according to relation (18).

Any computer program for self-regulation of the feed motor speed of the warping cylindrical drum based on relation (18) will comply with the decrease curves of the motor speed according to the lengths L_x registered during warping. The computer program can also be based on relation (17) if, during warping, the number N_x of wrapping rotations is registered.

Conclusions

Band warping machines with separate variable speeds, one for rotation and the other for the axial advance of the warping cylindrical drum, can achieve the self-regulation of these motors speeds through computer programs based on relations (10) and (18), if control of the regulation according to band length L_x wrapped on the cylindrical drum is possible. A computer program can be also conceived on the basis of relations (9) and (17), if a control is set according to the number of wrapping rotations N_x carried out on the cylindrical drum. Whichever the program variant selected, the effective density ρ_{eo} should be determined automatically at the beginning of the first band warping, as achieved with the Benninger-Ben –tronic machine. Other parameters specific to the machine or the warping do not require experimental determinations during warping.

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