CONTROL OF WINDING AND UNWINDING PROCESSES OF ROLL MATERIAL

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ABSTRACT
This article presents analytic equations describing the kinematics of the processes winding and unwinding of roll material. These equations are used for creation of mathematical model on the system, involving the variables initial and actual diameter of winding, linear velocity and band stretching. The main goal is establishing of methods for control of unwinding and winding by using torque and speed regulation.The obtained results will be used for further numerical controlling of these processes.

KEY WORD
Winding, unwinding, roll materials, dancer control.

INTRODUCTION
The unwinding and winding of roll material is a very important process for many manufacturing systems. In most of the cases, the quality of the processes depends mainly on the linear speed and tension of the material [1]. This means that the quality of the product depends on how well the speed and tension of the ribbon are regulated. Therefore, the motors used for the unwinding and winding processes must be operated very precisely [4, 5]. One of the aims of the control is to improve the management of the ribbon tension and winding speed, so the constant tension to be kept within the process of speed change. On controlling the process, the mechanical configuration of the machine, the properties of its elements, the deflection from the set linear speed and ribbon tension must be taken into account [2, 3].

Subject of this paper is the realization of a mathematical model for controlling the testing stand for winding and unwinding processes of roll material.

APPROACH
The testing stand of the processes winding and unwinding of roll material is shown in the diagram of *Figure 1*. The kinematic diagram of the facility is as follows.

For the proper functioning of the stand, it is necessary to constantly follow the speed of the ribbon and its tension. The two constants must not interact or their control methods must not allow the change of one at the account of the other. Because of this, the control of the process should be done independently by two power motors, each keeping constant the operating parameters as set. Here in after the control methods of these motors are discussed.

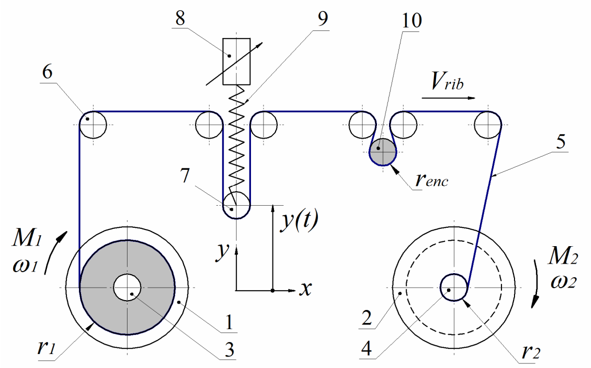

FIGURE 1. Testing stand of the processes winding and unwinding of roll material

Here the numbering is described with:
1 – unwinding roll;
2 – winding roll;
3 – unwinding motor;
4 – winding motor;
5 – roll material;
6 – leading rollers;
7 – dancer's roll;
8 – dancer;
9 – dancer's spring;
10 – rotary encoder.

I. Control of the winding process as per speed.

The linear speed of the ribbon V_{rib}, m/s, determined to the parameters of the winding motor 4 is as follows:

$$V_{rib}(t) = \frac{\pi r_2(t) n_2(t)}{30}, \; m/s, \tag{1}$$

Where $r_2(t)$ is the momentary radius of the winding roll, m;

$n_2(t)$ – the momentary speed of rotation of motor 4, rpm.

The momentary radius of the ribbon r_2 on the winding roll 2 is determined from:

$$r_2(t) = r_{2,start} + N_2(t)\delta_{rib}, \ m, \qquad (2)$$

where $r_{2,start}$ - initial radius of the winding roll, m;

$N_2(t)$ - the number of complete rotations of motor 4;

δ_{rib} - thickness of ribbon, m.

Replace Eq. (2) in Eq. (1) and obtain the real linear speed of the ribbon.

$$V_{rib}(t) = \frac{\pi(r_{2,start} + N_2(t)\delta_{rib})n_2(t)}{30}, \ m/s, \qquad (3)$$

To keep the constant speed of the ribbon, the setting of the speed to the motor looks as follows:

$$n_{2,set}(t) = \frac{30\,V_{rib,set}}{\pi(r_{2,start} + N_2(t)\delta_{rib})}, \ rpm, \qquad (4)$$

where $V_{rib,set}, m/s$ is the desired constant speed of the ribbon.

If the feedback on the linear speed of the ribbon is calculated on the basis of the rotation speed of the winding motor 4 - $n_{2,act}$, then for its actual value is obtained the following expression:

$$V_{rib,act}(t) = \frac{\pi(r_{2,start} + N_2(t)\delta_{rib})n_{2,act}(t)}{30}, \frac{m}{s}, \qquad (5)$$

The difference between the set and the actual linear speed of the ribbon represents the error ΔV, which must be minimized. Its constant is determined from:

$$\Delta V_{rib}(t) = V_{rib,set} - V_{rib,act}(t), \ m/s. \qquad (6)$$

In this case, the setting of speed in rpm to the winding motor must be recalculated as per the following equation, where are replaced Eq. (6) and Eq. (5) in Eq. (4):

$$n_{2,set}(t) = \frac{30V_{rib,set}}{\pi(r_{2,start} + N_2(t)\delta_{rib})} \pm \frac{30\Delta V_{rib}(t)}{\pi(r_{2,start} + N_2(t)\delta_{rib})} = \qquad (7)$$

$$= \frac{30(V_{rib,set} \pm \Delta V_{rib}(t))}{\pi(r_{2,start} + N_2(t)\delta_{rib})}, rpm$$

The main offset of this method is an option for regulating the ribbon speed only upon operating the complete motor revolution, which is a periodical uneven impact on the winding parameters.

In most of the cases, exterior sensors called encoders, position 10 in *Figure. 1*, are used for reporting the ribbon linear speed. They give a certain number of impulses per one revolution of their axis. The reporting of the number of revolutions is done on the basis of the difference $\Delta Incr$ between two positions of the encoder for a set, fixed time Δt.

$$\Delta Incr = EncIncr\ (t + \Delta t) - EncIncr\ (t), \ incr. \qquad (8)$$

Hence, for the linear speed of the ribbon calculated on the basis of the feedback of the encoder is obtained:

$$V_{rib,act_{enc}}(\Delta t) = \frac{2\pi r_{enc} \dfrac{\Delta Incr}{E_{res}}}{\Delta t}, \ m/s, \qquad (9)$$

where r_{enc} - the radius of the roll, mounted on the encoder axle, m;

E_{res} - encoder resolution, $incr/rev$.

Error ΔV, which must be calculated looks as follows:

$$\Delta V_{rib}(\Delta t) = V_{rib,set} - V_{rib,act_{enc}}(\Delta t), \ m/s. \qquad (10)$$

In this case, the setting as per speed in rpm to the winding motor must be recalculated by replacing Eq. (10) and Eq. (9) in Eq. (4):

$$n_{2,set}(t) = \frac{30(V_{rib,set} \pm \Delta V_{rib}(\Delta t))}{\pi(r_{2,start} + N_2(t)\delta_{rib})}, \ rpm. \qquad (11)$$

II. Control as per the moment of the unwinding process.

The tension of the ribbon F is a constant, which depend on the parameters of the roll material and of the unwinding system. In the process of unwinding of the roll material, the motor 3 must operate in a brake mode, providing in such a way a constant uniform tension. Because the operating radius of the unwinding roll $r_1(t)$ constantly decreases, then the brake torque of the motor must change in time. The tension of roll material is measured by a device called dancer, which can be realized in two diagrams – with linear displacement, *Figure. 2* or with rotary displacement, *Figure. 3* of the measuring element.

The feedback between the tension of the ribbon and the brake torque of the motor is obtained from the measurement of the potentiometer built in the dancer. The applied force to the ribbon F_{rib} obtains the following general shape:

$$F_{rib}(t) = \frac{F_0 + F_{spr}(t)}{2},\ N\ , \tag{12}$$

where $F_0 = mg + F_{0,spr}$, N is the force caused by the mass of the moving elements of the dancer mg and the force by the prior tension of its spring $F_{0,spr}$, N ;

$F_{spr}(t)$- the variable force, with which the dancer spring acts on the ribbon, N.

For *Figure. 2* the equation of the variable force of the spring looks as follows:

$$F_{spr}(t) = c_{spr}\, y(t),\ N\ ,$$

and for *Figure. 3*:

$$F_{spr}(t) = c_{spr}\, \varphi(t),\ N\ .$$

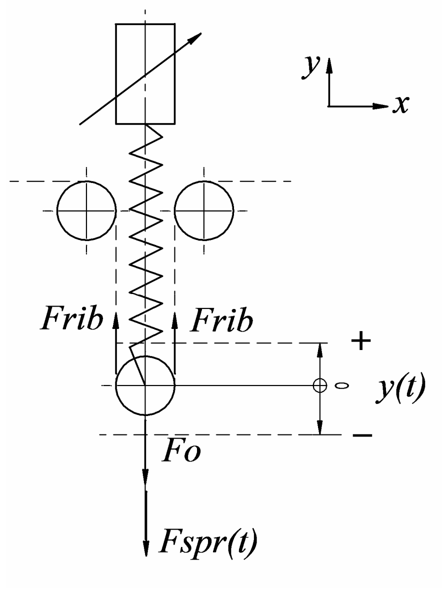

FIGURE 2. Dancer with linear displacement

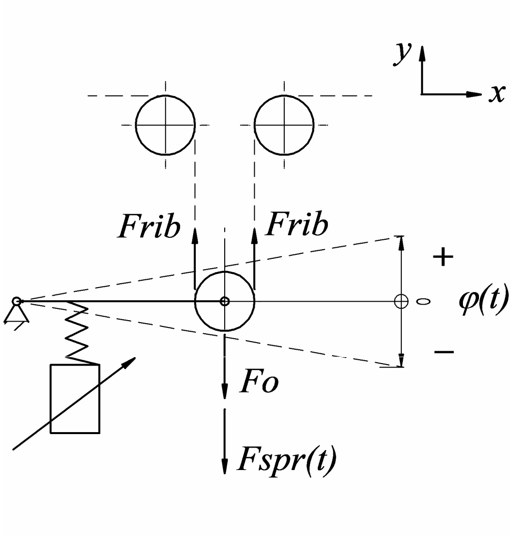

FIGURE 3. Dancer with rotary displacement

This force is determined by the stiffness of the spring c_{spr} and the working stroke of the dancer $y(t)$ or $\varphi(t)$.

According to the change in the force of the ribbon and the momentary radius of the unwinding roll $r_1(t)$, the setting as per the momentum to the motor 3 must be changed.

$$M_1(t) = F_{rib}(t) r_1(t),\ Nm\ . \tag{13}$$

The momentary radius of the ribbon r_1 on the unwinding roll 1 is determined from:

$$r_1(t) = r_{1,start} - N_1(t)\delta_{rib}\ ,\ m\ , \tag{14}$$

where $r_{1,start}$ - initial radius of the unwinding roll, m;

$N_1(t)$ - the number of the complete revolutions of motor 3;

δ_{rib} - thickness of the ribbon, m.

Replace Eq. (14) in Eq. (13) and obtain the actual torque applied by the force in the ribbon to the unwinding roll.

$$M_1(t) = F_{rib}(t)(r_{1,start} - N_1(t)\delta_{rib}),\ Nm\ . \tag{15}$$

The difference between the set F_{set} and the actual tension of the ribbon is the error ΔF, which must be minimized. Its constant is determined from:

$$\Delta F_{rib}(t) = F_{rib,set} - F_{rib,act}(t),\ N\ . \tag{16}$$

In this case, the setting as per torque in *Nm* to the unwinding motor must be recalculated as per the following equation, where is replaced Eq. (16) in Eq. (15):

$$M_1(t) = \left(F_{rib,set} + \Delta F_{rib}(t)\right)\left(r_{1,start} - N_1(t)\delta_{rib}\right),\ Nm \quad (17)$$

CONCLUSIONS

The discussed methods for control of the unwinding and winding processes find wider applications in the paper, textile and packaging industries. The choice of a control method depends on the specific proposal and its requirements. The worked out equations Eq. (11) and Eq. (17) allow the maintenance of consistency of the set parameters of the chosen control process. They are constant in time t and offer the option for easy resetting in changing the input parameters $V_{rib,set}$ and $F_{rib,set}$.

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