Tension Control: Open-Loop Torque Control in Material Unwinding Process

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Abstract: This paper analyzes the problem of tension control in the processes of unwinding, rewinding, and winding materials, addressing how to implement such control in an open-loop system without the commonly used dancer rolls. It describes the theoretical and mathematical foundations of material tension control. An example problem of tension control on a real control object has been solved. An algorithm utilizing the torque control method in an open-loop system, which uses only servo drives to manage tension, is presented. This algorithm allows for increased process speed by unwinding two material rolls simultaneously, a capability that was not possible with single dancer roll control. Additionally, an algorithm for measuring the moment of inertia of material rolls using servo drives is discussed. The necessary measurements for the control algorithm to function effectively have been performed. The article concludes by presenting the results.

Keywords: tension control, torque control, rewinding, unwinding

1. Introduction

The production of various types of papers, fibers, films, and cables requires effective tension control. The material should not excessively stretch, tear, or, on the other hand, become loose. Factors such as varying friction resistances, moments of inertia of machine parts and material rolls, methods for measuring or estimating tension, proper control of unwound and wound material, and tension generation on the material itself all pose challenges in tension control.

There are many methods and technical solutions for addressing these problems. Different technologies and control strategies – such as PID, Fuzzy PID, neural networks, and genetic algorithms – are analyzed and summarized in [1]. Two key issues discussed there are the influence of winding radius on motor speed control accuracy and technologies for damping tension vibrations.

A fuzzy PID controller has also been analyzed and implemented for coil winding in transformer manufacturing [2]. This paper presents a mechanical structure and tension control scheme of a transformer winding machine, focusing on the synchronous winding control problem of the conductor and insulating layer.

A constant tension control system is proposed in [3] to improve the quality of high-voltage coils in transformers. The active disturbance rejection control, together with the Smith predictor, has been adopted there to achieve better quality than a PID-based classical control system.

Tension modeling and precise tension control of roll-to-roll systems have also been the subject of interest and in-depth analysis in [4]. This study analyzes factors affecting changes in tension and develops a tension model for each section of the machine, allowing for both velocity and torque control methods in a roll-to-roll system for flexible electronics.

In practice, a successful solution to these problems and effective tension control can be achieved only with the appropriate equipment and control systems. Usually, any changes in the process or the machine's configuration require significant modifications to the control strategies. However, altering the machine may be costly or physically impossible, presenting an additional challenge to software and control algorithms.

This paper presents and analyzes such a problem. The goal was to increase machine efficiency by unwinding two material rolls simultaneously instead of one. This solution required either the use of two dancer rolls or the elimination of the existing one. Unfortunately, unwinding two material rolls on a single dancer roll caused the materials to wrap and flex around each other, necessitating a control strategy that operates without any dancer roll.

Many unwinding processes utilize dancer rolls [5–8]. If a dancer roll cannot be used, the next option may be to implement a tension detector. However, both solutions may be impractical for existing machines, and modifying the machine could be costly. The removal of the dancer roll and tension detector presents a significant challenge, as there is no mechanism to prevent differences in linear speeds between the unwinding and winding sides, nor to mitigate jerks and overloads [9].

Therefore, a control system must be implemented that effectively drives the material rolls to prevent excessive tension and slows down the roll at the end of the process to avoid mate-

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rial sagging. Rolling resistance, which depends on rotational speed, should also be considered and compensated accordingly.

This article focuses on utilizing only control devices such as servo drives, inverters, or powder brakes to control tension. These devices generate specific braking or driving torque based on estimated moments of inertia and rolling resistance. The developed system successfully meets the process goals, speeding up the process and enhancing overall efficiency.

In the following sections of this paper, we present the results of the tension control analysis of the unwinding process implemented in one of the companies in the northwestern part of Poland. Sections 2 and 3 discuss the analyzed tension control methods and their variations during machine operation. Section 4 describes the machine and the unwinding process. Sections 5 and 6 are devoted to the theoretical analysis of the process. The measurements and system implementation are detailed in Sections 7 and 8. The article concludes with a summary of the results and some concluding remarks.

2. Tension control methods

Two main tension control methods are distinguished: speed control method and torque control method:

A. Speed control with a dancer roll

In this method, the speed of the unwinding or winding motors is controlled to stabilize the process. Tension in the material is primarily caused by the weight of the dancer roll suspended on it. The movement of the dancer roll results from the variable length of the material between guide rolls, as shown in Fig. 1.

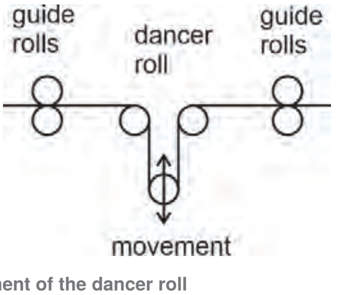

Fig. 1. Movement of the dancer roll
Rys. 1. Ruch rolki naprężającej

In other words, if the linear speed of the winding side equals the linear speed of the unwinding side, the dancer roll will maintain its position. However, if the winding side's speed exceeds that of the unwinding side, the dancer roll will move upward until the speeds are equal.

When using speed control, stability of movement is maintained even if the tension caused by inertia or friction varies. However, since it is not possible to adjust only the torque to control tension, the accuracy of tension regulation is relatively low. Tension can be controlled by changing the mass of the dancer roll or by pressurizing an air cylinder. Increasing the mass of the dancer roll also increases its inertia, leading to a slower response to movement and resulting in tension fluctuations [6, 7].

There are also methods that utilize a spring to primarily generate tension in the material, or those that employ an electromagnetic clutch and motor.

B. Torque control without dancer roll

In this method, the torque required to control the tension is controlled. It is possible to control:
- Torque caused by inertia of the material rolls, the motor, and the shaft,
- braking torque dependent on rolling resistance,
- braking torque generated by an actuator.

Torques generated by rolling resistance or inertia moments are compensated. For torque control, devices such as electromagnetic brakes and clutches, servo drives, or inverters can be used as needed; these devices generate specific braking or driving torque [10, 14]. Even when rotational speed changes, the desired tension can be achieved to some extent by adjusting the braking or driving torque.

There are three main methods of torque control: manual control, open-loop control, and closed-loop control. Manual control involves applying voltage to the electromagnetic brake or clutch based on the roll diameter, using a potentiometer. In open-loop control, the roll diameter is measured using a sensor, and the braking torque is regulated accordingly, which is directly proportional to the diameter. Closed-loop control directly monitors the tension of the material using a tension detector. This method is the most accurate but also the most expensive.

C. Speed control and torque control comparison

Speed control is recommended in situations where short acceleration and deceleration ramps are desired, where very accurate roll diameter measurement is unavailable, or when the process is conducted at very low tension or speed.

In torque control, managing tension can be challenging due to the significant influence of inertia moments during short ramps. The control of very low tension or processes at low speeds is also limited by the cogging torque of servo drives [11]. Additionally, inaccurate measurement of roll diameter can significantly affect material tension errors.

The advantage of torque control lies in its accuracy; tension is a direct result of the actuator torque, whereas in speed control, tension is influenced by the mass of the dancer roll.

3. Tension fluctuations

Fluctuations in tension always affect the quality of the process and the final product. Four main components can be identified that cause deviations from the desired tension [12]:

A. The material used in the process contributes to deviations from the desired tension value and can induce oscillations. If the material roll is wound with uneven tension, it may lead to tension fluctuations during unwinding and subsequent processing. Different materials have varying Young's modulus and viscosity modulus, which also impact these fluctuations.

B. Winding speed and tension are strongly interdependent. A difference in linear speed between the unwinding and winding sections results in changes in tension.

C. Another contributing factor is the changing radius of the unwound or wound roll, along with inaccuracies in measuring this radius. Measurement errors can affect motor torque calculations, leading to tension fluctuations. As the roll unwinds, its radius decreases, which in turn reduces the moment of inertia. The moment of inertia during the process can be described by the following formula:

$$J(t) = \frac{1}{2}\rho\pi d\left(r_1^4(t) - r_2^4\right), \tag{1}$$

where ρ is the material density, d is the roller width, r_1 is the radius of the roll at the current time, and r_2 is the radius of the shaft on which the roller is mounted. The moment of inertia can be determined using formula (1), assuming a constant density for the material roll. This moment of inertia affects the operation of the motor.

If the motor does not compensate for the influence of the moment of inertia of the material roll as it varies with the radius, tension fluctuations are likely to occur. It is important to note that the accuracy of radius measurement has a significant impact on control quality, as the radius is raised to the fourth power in the formula.

D. Equipment inaccuracies, such as uneven guiding or driving rolls, motor vibrations, and other disturbances, also contribute to tension fluctuations.

4. Control object and problem description

The control object in this work is a machine designed for unwinding abrasive paper from rolls and cutting segments of this paper to a specified length, located in one of the companies in the West Pomeranian region of Poland. The scheme of the machine is shown in Fig. 2.

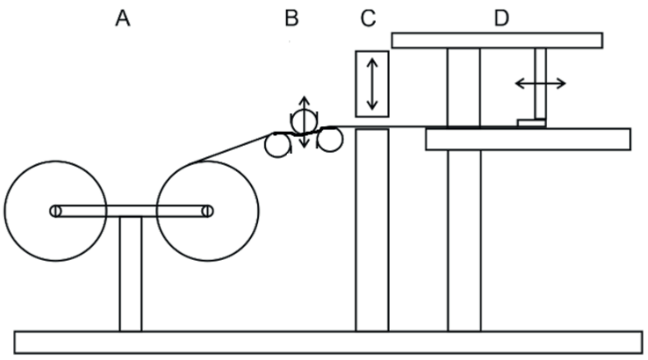

Fig. 2. Control object – machine for unwinding and cutting abrasive paper belts to a specified length
Rys. 2. Obiekt sterowania – maszyna do rozwijania i cięcia pasów papieru ściernego na określoną długość

The machine has been designed to unwind a single roll of material in speed control mode using a dancer roll. Its main components consist of:

A. Two shafts coupled with servo drives that unwind the rolls of material (unwinders),
B. A dancer roll,
C. A guillotine that cuts the material to the specified length,
D. A clutch that pulls out the material to the specified length.

To improve the production process without incurring excessive costs, it was decided to unwind two rolls simultaneously without investing in a second dancer roll. This change involves eliminating the dancer roll, with the task of controlling tension being managed by the servo drives of the unwind shafts. Unwinding two materials on a single dancer roll would cause a flexing effect between them. As can be seen in Fig. 2, in contrast to the typical operation of the dancer roll shown in Fig. 1, this was raised all the way up, so that it only lightly touched the material, which slightly dampened the vibration. It now has no tensioning function. Consequently, the control strategy was shifted from speed control to torque control. The servo drives compensate for rolling resistance and moment of inertia in real time.

Process with a dancer roll

While pulling out the material using the clutch, the encoder detects changes in the position of the dancer roll. Based on this information, the controller issues a speed signal to the unwind servo drive. Eventually, the position of the roll stabilizes at a specific point, resulting in equal linear velocities for both the clutch and the unwind.

Additional tension in the material arises from the acceleration of the dancer roll. Consequently, the heavier the dancer roll, the greater its inertia, leading to even higher additional tension. To compensate for this extra tension with a heavier roller, it would be necessary to extend the acceleration ramps, which in turn slows down production. In speed control, achieving precise tension control is not feasible. Shorter acceleration ramps lead to greater tension fluctuations during the unwinding process, potentially compromising product quality. Stretchable papers are particularly susceptible to this issue; at high line speeds, such paper can stretch by up to 2 mm per meter, which is unacceptable.

Reducing the line speed and minimizing the moment generated by the electromagnetic clutch of the dancer roll during unwinding extends production time. Additionally, changing the dancer roll to one with a different weight is not feasible.

Process without a dancer roll (torque control)

Eliminating the dancer roll necessitates a change in the control method from speed control to torque control. The optimal solution would involve closed-loop control with a tension detector. However, this article presents a method that operates without a tension detector, meaning the process must be conducted in open-loop torque control mode. The assumptions for the developed control algorithm are as follows:

- unwinding material rolls using the clutch without a dancer roll,
- maintaining a constant, as low as possible tension on the material during the unwinding process,
- allowing two rolls to be unwound simultaneously.

To provide stable unwinding of a material roll without a dancer roll, it is essential to maintain a constant tension on the material, regardless of the factors that cause tension fluctuations. The clutch that pulls the material exerts force on the unwinder, causing it to rotate. Without effective tension control, the proper execution of this process becomes practically impossible. During acceleration, the material tension could become excessively high, potentially leading to material breakage. Conversely, during deceleration, material sagging could occur due to the large moment of inertia of the unwinder and the material roll.

Figure 3 illustrates an example of the clutch's linear speed profile during the unwinding process.

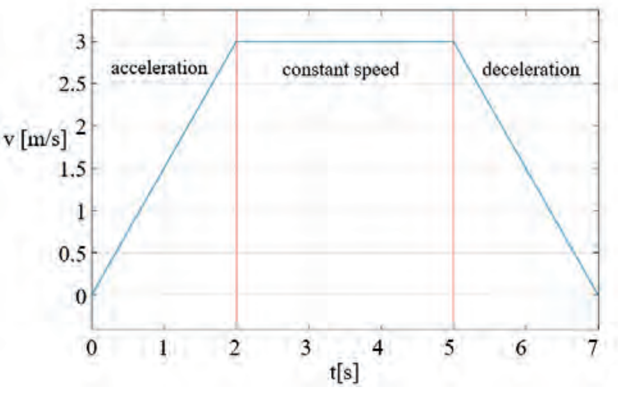

Fig. 3. An example of linear velocity profile of the clutch
Rys. 3. Przykład liniowego profilu prędkości sprzęgła

The ideal solution is to ensure that the linear speed on the unwinder side matches the linear speed on the clutch side while maintaining a constant tension on the material. If the speed profile on the unwinder side is below that of the clutch side, the material will stretch; if it is above, the material will sag.

Figure 4 illustrates an example of the required torque profile to maintain constant, non-zero tension in the material. In

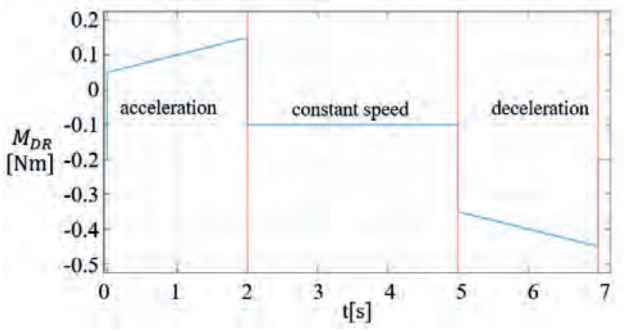

Fig. 4. Example of required moment profile to maintain constant, non-zero material tension

Rys. 4. Przykład wymaganego profilu momentu w celu utrzymania stałego, różnego od zera naprężenia materiału

this context, positive torque causes rotation in the direction of material unwinding, while negative torque acts in the opposite direction.

The goal of the control system is to compensate for the influence of the moment of inertia and rolling resistance by specifying the appropriate value of braking or driving torque on the unwinder servo drive, thereby maintaining constant tension throughout the unwinding process. This specified torque must also be adjusted based on the current roll diameter.

Assuming the material is not stretchable, the clutch's linear acceleration can be translated into a specified angular acceleration of the unwinder, depending on the roll diameter. The value of the clutch's linear acceleration is used to calculate the torque needed to compensate for the effects of inertia. The compensated servo drive torque must also account for the torque required to maintain non-zero tension on the material.

To precisely compensate for the influence of the moment of inertia of the material roll, knowledge of the roll's mass and dimensions is essential. To avoid investing in additional weighing equipment, an algorithm has been implemented to test the moment of inertia of the material roll. This is based on measuring the angular acceleration at a constant specified torque on the unwinder servo drive with the material roll installed. After the test, the moment of inertia of the entire unwinder mechanism and the material roll is obtained.

By knowing the roll's width, the unwinder's moment of inertia, and the roll's diameter, the material's density and mass can be determined. With this information, the real-time moment of inertia of the material roll is calculated and compensated for during the process. The mathematical description will be provided in the subsequent sections of this work.

5. Mathematical description of tension control

Assuming that a positive torque will create material tension (rotation in the opposite direction to unwinding), the following relationship is established:

$$M_{DR} = M_N - M_B - M_O, \tag{2}$$

where M_{DR} is the value of unwinder servo drive torque, M_N is the torque causing the desired material tension, regardless of diameter, M_B is the inertia compensating torque, M_O is the rolling resistance compensating torque, according to the Coulomb friction model, considering viscous friction [13], assuming movement only in the unwinding direction. The torque causing the desired material tension is determined by the formula:

$$M_N = F \cdot r, \tag{3}$$

where F is the given tension force on the material, r is the material roll radius.

The actual tension on the material during the process may vary slightly from the specified value, with factors affecting this deviation described in detail in Chapter 3.

$$M_B = I_U \cdot \alpha_O, \tag{4}$$

where I_U is the moment of inertia of the entire unwinder system and material roll, α_O is the angular acceleration of the unwinder.

The moment of inertia of the entire unwinder system and material roll is determined by the formula:

$$I_U = I_O + I_M, \tag{5}$$

where I_O is the moment of inertia of the unwinder, I_M is the moment of inertia of the material roll.

The angular acceleration of the unwinder is described by the formula:

$$\alpha_O = \frac{a_C}{r}, \tag{6}$$

where a_c is the linear acceleration of the clutch.

The rolling resistance torque is given by the relationship:

$$M_O = B \cdot \omega + c, \tag{7}$$

where B is the Coulomb friction coefficient of the unwinder system, ω is the angular velocity of the unwinder, and c is the viscous friction coefficient.

With a given non-zero tension force F, the unwinder will be tensioning the material at standstill and the value of M_{DR} will be positive. During motion, it may turn out that the moments M_B or M_O will cause the value of M_{DR} to be negative, in which case the unwinder will "assist" in driving the roller.

6. Mathematical description of the material roll inertia test

The inertia moment test of the material roll involves determining the material's density, the initial mass, and subsequently calculating the roll's moment of inertia in real time based on its diameter. Due to the low angular velocities during the test, rolling resistance is neglected. The moment of inertia can be determined using the following formula:

$$I = \frac{M_{pk}}{\alpha_O}, \tag{8}$$

where M_{PK} is the specified, constant torque applied to the servo drive, and α_O is the angular acceleration of the unwinder during the test.

The moment of inertia of the material roll is described by the formula:

$$I_{Mp} = I - I_O, \tag{9}$$

where I_{Mp} is the initial moment of inertia of the material roll, I is the moment of inertia determined during the test with the roll attached, and I_O is the moment of inertia of the unwinder without roll.

The moment of inertia of the unwinder was determined using formula (8), without the roll attached. It is enough to do it once for a given shaft as this value is constant.

The same experiment with the roll attached allows one to calculate density of the material roll, necessary to calculate varying moment of inertia of the unwinded material roll. Figure 5 illustrates the unwinder shaft with the material roll attached.

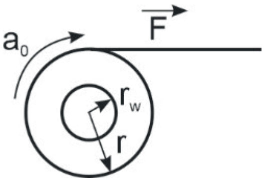

Fig. 5. Unwinder shaft with the material roll attached
Rys. 5. Wał odwijający z zamocowaną rolką materiału

By knowing the moment of inertia of the roll and its dimensions, the initial mass of the roller was calculated by transforming the general formula for the moment of inertia of a hollow cylinder. This process allowed for the determination of the initial mass of the roller with the material.

$$m_p = \frac{I_{Mp}}{\frac{1}{2}\left(r^2 - r_w^2\right)}, \tag{10}$$

where r is the radius of the roller, r_w is the radius of the unwinder shaft.

The volume of the roller is in accordance with the formula:

$$V = \pi d\left(r^2 - r_w^2\right), \tag{11}$$

where V is the volume of the roller, and d is the width of the roller.

To calculate real time moment of inertia of the roll during unwinding, the material density was determined according to the formula:

$$\rho = \frac{m_p}{V_p}, \tag{12}$$

where V_p is the initial volume of the roll, and m_p is the initial mass of the roll.

Real time roll mass during the process is calculated according to the formula:

$$m = \rho \cdot V, \tag{13}$$

where V is the real time volume of the roll determined based on the measurement of the radius using an ultrasonic sensor.

Moment of inertia of the material roll during unwinding is calculated in real time according to the general formula for the moment of inertia of a hollow cylinder:

$$I_M = \frac{1}{2} m\left(r^2 + r_w^2\right), \tag{14}$$

After substitution, the following formula is obtained:

$$I_M = \frac{1}{2}\rho\pi d\left(r^4 - r_w^4\right). \tag{15}$$

Since the radius of the roll is raised to the fourth power, even minor measurement inaccuracies can result in significant errors. So to minimize this uncertainty the measurement of the radius value of the roll is being caried out while at rest, after completing a cycle and the roll is in a standstill, and using this value before starting the next cycle. This approach is very effective for short strips of unwound material. However, for very long segments, it would be advisable to invest in an accurate measurement system.

For a given and parameters and c of the eq. (7) before each cycle we measure radius and calculate current moment of inertia (15). This, together with the known (assumed) linear velocity profile of the clutch (as in Fig. 3), allows one to live calculation of the inertia compensating torque (4) and the rolling resistance torque (7). All this, for a desired material tension force (maximal allowed for the material not to burst or slipping out of the grip) and desired material tension torque (3) allows one to calculate driving torque of the unwinder.

7. Experiment – rolling resistance measurements

To be able to compensate for the influence of the rolling resistance of the unwinders, their measurements were carried out. A constant rotational speed was set and the current servo drive torque was read. Several measurements were taken for different rotational speeds. Figure 6 (a) shows the plot of the measured rolling resistance moments depending on the rotational speed.

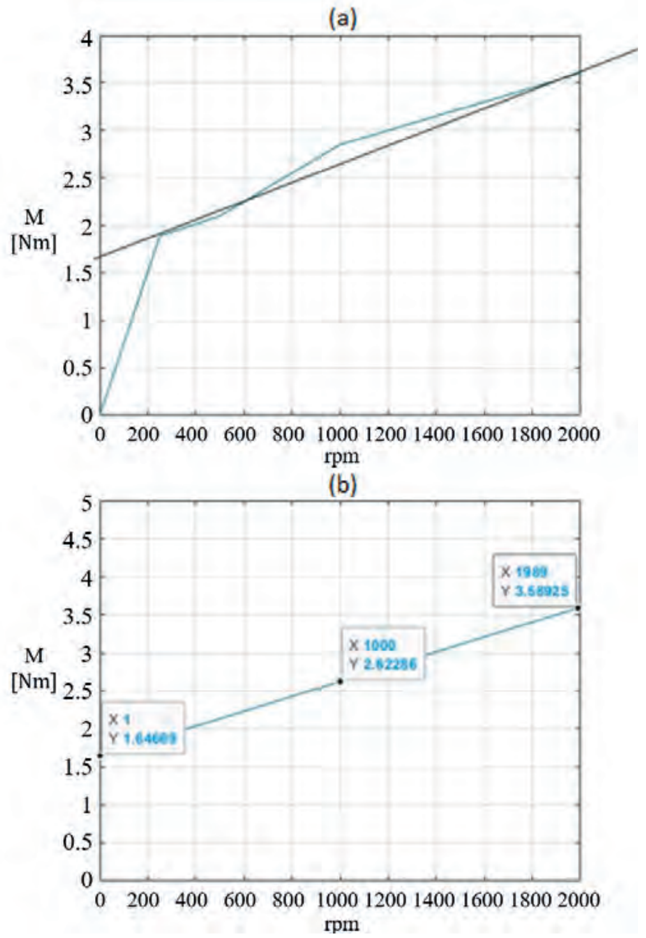

Fig. 6. (a) A plot of torque measurements due to rolling resistance of the unwinder as a function of rotational speed; (b) parameters of the rolling resistance approximation
Rys. 6. (a) Wykres pomiaru momentu obrotowego wynikającego z oporu toczenia odwijarki w funkcji prędkości obrotowej; (b) parametry przybliżenia wartości oporu toczenia

The first speed for which torque due to rolling resistance was recorded was 250 rpm, and measurements were taken up to a speed of 2000 rpm. A straight line that approximates the results was overlaid on the graph. In Fig. 6 (b) the approximation of results was shown.. Based on the determined, approximated straight line, according to equation (7), the Coulomb friction coefficient of the unwinder system B = 0.000977 and the viscous friction coefficient c = 1.645713 were determined [13].

8. Experiment – inertia moment test

The tension control algorithm and the inertia moment test were implemented in the PLC controller of the control object. Due to the time-critical nature of the algorithm, communication between the PLC controller and the servo drives occurs in isochronous real-time (IRT) mode. In this mode, the program cycle, communication bus, signal reading, and processing are synchronized, allowing data exchange to take place within a single program cycle at a constant time interval.

The inertia moment test described at the beginning of the section 6. Practically it may take no more than few hundreds of ms. In a presented bellow example it is 400 ms, so it may be easily taken before working with the new material roll. Here a torque of 9 Nm is applied to the unwinder servo drives, causing the unwinders to accelerate. After 100 ms of movement, acceleration is measured in a time interval of 300 ms. Figure 7 illustrates the recorded results of the inertia moment test, where the red line represents the set static torque, and the green line indicates the rotational speed of the unwinder. The difference between t1 and t2 is dt = 300 ms. Angular acceleration is calculated based on the difference between the final and initial velocity in the given time interval.

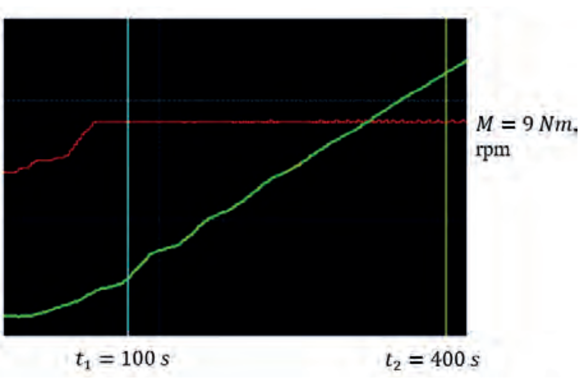

Fig. 7. Graph of the conducted moment of inertia test from the V-ASSISTANT program
Rys. 7. Wykres przeprowadzonego testu momentu bezwładności z programu V-ASSISTANT

9. Results

To confirm the operation of the algorithm, measurements were taken of the torque applied to the unwinder servo drives during the process cycle, checking whether the torque profile aligned with expectations. Additionally, measurements of the lengths of the finished, cut strips were conducted to verify that their dimensions fell within tolerance.

Using the V-ASSISTANT program, a torque profile graph for the process was created. Figure 8 displays the graph, where the red line represents the torque of the servo drive over time, and the green line indicates the angular velocity of the unwinder (rpm scale and time units purposely hidden). The recorded section pertains to the moment when the clutch pulls the material to the desired length. The desired effect is evident in the graph: during acceleration, the desired torque quickly reaches approximately 1.9 Nm in the direction of unwinding the material to compensate for inertia, then slightly increases as speed gains to further counteract rolling resistance.

Upon reaching the desired machine speed, the rolling resistance was significant enough that the desired torque settled around 0.7 Nm in the unwinding direction, indicating that the unwinder continues to assist in unwinding the material. Only during the deceleration phase does the unwinder begin to exert torque in the opposite direction to slow down. If the torque value responsible for slowing down were too low, the material could sag, as the clutch would stop faster than the unwinder, which has high inertia. The desired torque during the initial phase of braking was around -1.3 Nm, approaching -2 Nm toward the end. After coming to a complete stop, the material is gently tensioned with a predetermined tension force.

It is important to note that the desired torque values continuously depend on the diameter of the roller with the material. In this case, as shown in Fig. 8, this diameter was approximately 120 mm. The torque and speed oscillations of the unwinder are also visible in the graph; however, they did not negatively impact product quality or process stability. Although variations in material tension undoubtedly occurred, as indicated by the graph, accurately assessing these variations is challenging due to the open-loop control and the lack of feedback on the tension value. Nevertheless, based on observations of the machine's operation and its stability, it was assumed that these variations were negligibly small and did not affect the quality.

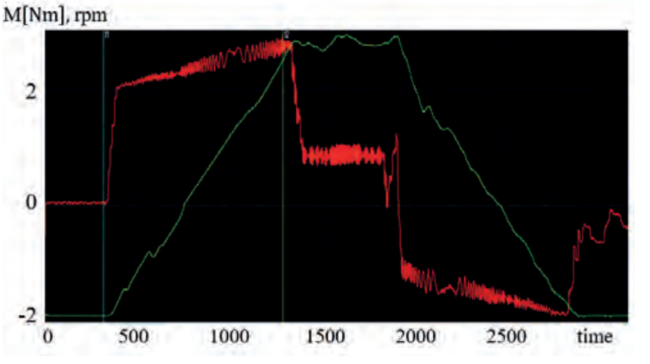

Fig. 8. Waves of the torque of the unwinder servo drive (red) and the angular speed of the unwinder (green) during the full-speed process
Rys. 8. Wykres momentu obrotowego serwonapędu odwijarki (czerwony) i prędkości kątowej odwijarki (zielony) w procesie przy pełnej prędkości pracy

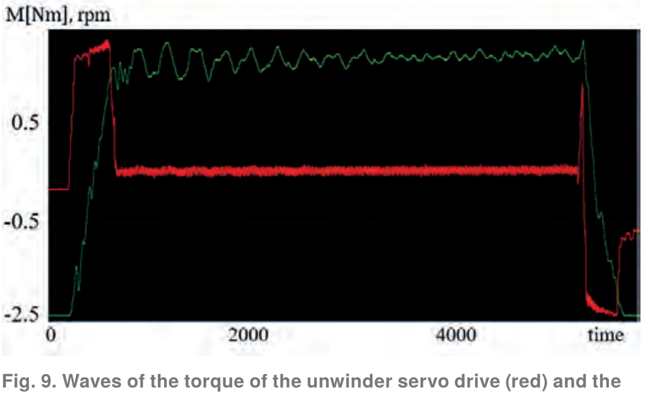

Fig. 9. Waves of the torque of the unwinder servo drive (red) and the angular speed of the unwinder (green) during the 10 % speed process
Rys. 9. Wykres momentu obrotowego serwonapędu odwijarki (czerwony) i prędkości kątowej odwijarki (zielony) w procesie z prędkością 10 %

A measurement was also taken at 10 % speed, with the results shown in Fig. 9. It is evident that the rolling resistance is significantly lower compared to the graph at 100 % speed.

The allowable tolerance for cut strips is 0.1 %. Measurements of strips of various lengths and different elasticity coefficients were conducted, all of which fell within the acceptable tolerance limits. The machine successfully unwinds two rollers simultaneously in a stable manner, without jerks, effectively increasing machine efficiency to 200 % of its initial performance. Furthermore, the algorithm enables achieving higher speeds than originally possible, without adverse negative effects. For belts measuring 1900 mm in length, cycle times were reduced by 9.6 % due to the enhanced working speeds.

Deviations in the length of the cut strip from the desired length are most noticeable with stretchy materials. In such cases, the desired tension force had to be reduced compared to less elastic materials to avoid exceeding the tolerance limit.

10. Conclusions

A system for controlling tension without a dancer roll has been successfully demonstrated using a torque control method and two servo motors. The mathematical algorithm for tension control in this torque control system has been detailed, and the necessary measurements for algorithm implementation have been conducted.

The open-loop torque control algorithm has been applied to a sample machine with the dancer roll disabled, allowing for the simultaneous unwinding of two material rolls and a reduction in cycle time. As a result, machine efficiency increased to 221 % of its initial performance, considering both simultaneous unwinding and the shortened cycle time. The benefits of these changes significantly outweigh the minor increase in setup time.

Torque control may be necessary in situations where it is physically impossible to install multiple dancer rolls or when such an installation is economically unjustified. The stable operation of the machine, along with the final product meeting tolerance limits, confirms the effectiveness of the control algorithm. This algorithm can be applied to both unwinding and rewinding material systems.

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Kontrola naprężeń: sterowanie momentem obrotowym w pętli otwartej w procesie odwijania materiału

Streszczenie: W artykule analizuje się problem sterowania naprężeniem w procesach odwijania, przewijania i nawijania materiałów, omawiając sposób wdrożenia takiego sterowania w układzie pętli otwartej bez powszechnie stosowanych rolek naprężających. Opisuje się teoretyczne i matematyczne podstawy sterowania naprężeniem materiału. Rozwiązano przykładowy problem sterowania naprężeniem na rzeczywistym obiekcie sterowania. Przedstawiono algorytm wykorzystujący metodę sterowania momentem obrotowym w układzie pętli otwartej, który wykorzystuje wyłącznie serwonapędy do sterowania naprężeniem. Algorytm ten umożliwia zwiększenie szybkości procesu poprzez jednoczesne odwijanie dwóch rolek materiału, co nie było możliwe przy sterowaniu jedną rolką naprężającą. Ponadto omówiono algorytm pomiaru momentu bezwładności rolek materiału przy użyciu serwonapędów. Przeprowadzono niezbędne pomiary, aby algorytm sterowania działał skutecznie. Artykuł kończy się przedstawieniem wyników.

Słowa kluczowe: sterowanie naprężeniem, sterowanie momentem obrotowym, przewijanie, odwijanie

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