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Study of tension control systems for automatic rotogravure machines

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Abstract: In the manufacturing sector, a large number of machines today use automation technologies. Production will grow and speed up thanks to automation technologies, which include using rotogravure machines. A machine using a printing technique known as a rotogravure machine is frequently used to print packaging on materials like paper or plastic. No one presently makes fully automatic rotogravure machines in Indonesia. Tension control is one of the automation systems of a rotogravure machine. In this research, tension control, kinds of tension control, and the building of a rotogravure machine tension control system are all topics that will be covered. It uses a descriptive qualitative approach. Employing a literature review to gather data and descriptive statistics to analyze it. The study's findings demonstrate that the rotogravure machine is a fast-printing device that uses substrates like paper, aluminum, and plastic. The printing procedure begins with the unwinding roll, moves to the infeed, and then continues with the first and second color printing processes, moving as necessary to the outfeed and rewinding roll using a tension control mechanism. The roller-to-roll mechanism used by the machine allows for tension management because the printed material is subjected to varying strains that must be managed. A rotogravure machine can use four different forms of tension management, specifically speed control for unwinding and rewinding, speed control for unwinding and torque control for rewinding, and speed control for unwinding and rewinding. Development of a tension control system on a rotogravure machine using PLC and HMI as the main controller on the machine.

Keywords: Control; tension; printing machine; rotogravure

1. INTRODUCTION

We're in the fourth industrial revolution right now [1][2]. Many manufacturing businesses have adopted automation technology in the fourth industrial revolution [3][4][5]. A Technology known as automation involves the use of machines, electronics, control systems, and computers [6]. The production process can be managed by the automation system [7]. Time can be saved and output can be increased in an automated production process. Components including sensors, controllers, and actuators are needed for machine automation. The food packaging sector is one of those that is expanding. The purpose of packaging is to safeguard the product and raise its market value. We require packaging printing equipment for that.

The printing device's capacity and output rate determine its final result. The structure of the current printing press is quite intricate, with just one set of controllers [8]. Because printing is such a dynamic and inventive process, printing technology has made significant strides in the automation field [9]. In the printing industry, rotogravure machines are used to print packaging. Indonesian rotogravure technology is still semi-automatic, and the printing pace is often slow. Additionally, the machine's ability to control its precision is restricted.

A rotogravure machine is a printing device that is frequently used to print flexible materials for packaging, including metal, paper, and plastic [10]. The rotogravure printer offers benefits including quick printing, vibrant color, large print areas, thick ink layers, good dot reproducibility, and stable quality. Several control mechanisms, including color control (register control), tension, and temperature control for drying after printing, are supported by an automatic rotogravure machine. The gravure printing machine's tension management technology is crucial. The main element to ensuring printing quality is stable printing tension [11].

The majority of the equipment used in automatic rotogravure printing is imported. Superior human resources are required to meet the difficulties of the industrial period 4.0 and to assist the government program Making Indonesia 4.0, one of which is in the area of automation and control systems [12][13]. A technology called tension control is frequently utilized in industries including textiles, paper, and plastic films [14]. Because it serves as a guide for the machine's control registers, the tension control system is crucial to production [15]. Tension control is a control method that allows for flexible tension changes during winding. In this research, tension control, kinds of tension control, and the building of a rotogravure machine tension control system are all topics that will be covered. The creation of a tension control system for six-color rotogravure machine automation is an innovative aspect of this research.

2. METHOD

It uses a descriptive qualitative approach. The rotogravure machine's working mechanism, components, kind of control, and controls utilized on the rotogravure machine, as well as the development of the automatic rotogravure machine were all examined for the purpose of this study's data collecting. The concept of how a rotogravure machine operates, the tension control on the machine, the many methods of control, and the development of an automatic rotogravure machine are all described using descriptive statistics from data analysis.

3. RESULTS AND DISCUSSION

3.1 Rotogravure machine

A rotogravure machine is a fast printing device that prints on things including paper, aluminum, and plastic. Unwinding, tension control, register control, and rewinding are all parts of the rotogravure machine. Unwinding and rewinding on manual rotogravure machines employ an open loop mechanism. Print quality on rotogravure machines is influenced by the printing method, substrate, cylinder, ink, and print preparation.

Gravure printing is a long-run printing method that produces images that are crisper, smoother, and clearer. Using fast-drying inks, the gravure printing technique is frequently employed to print large quantities of packaging, wallpaper, and gift wrapping. Products with gravure printing include periodicals, greeting cards, wallpaper, wrapping paper, and food packaging. Image preparation, cylinder preparation, printing, and finishing are the production stages in a gravure printing operation [16].

The apparatus in **Figure 1** explains the rotogravure printing procedure. The printing medium (either plastic or paper), the gravure cylinder, the impression roll, the doctor blade, and the ink are the five major parts of gravure printing. The doctor's blade's job is to remove ink from the plate cylinder's surface, leaving only the little cells of the cylinder with ink. To achieve uniform contact with the cylinder, pressure is applied to the doctor's blade [17].

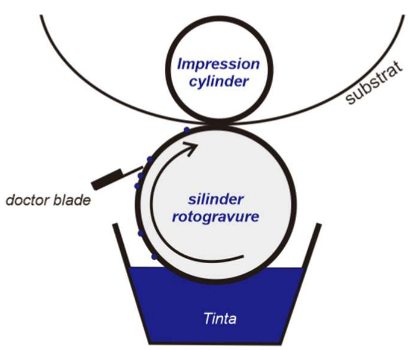

Figure 1. Rotogravure printing mechanism [18].

Making a cylinder with the engraved picture that will be printed is the first step in gravure. Cells that will hold the ink for transfer to the substrate will be created on the surface of the cylinder during the engraving process. The diameters of the cells must be carefully controlled since the amount of ink contained in each cell correlates to the various intensity of the color on the paper: deeper or larger cells will produce more vivid colors, while smaller cells will produce less brilliant colors. Typically, copper is plated on steel to make gravure cylinders. Laser or chemical engraving is used to create the desired pattern [19]. Making rotogravure cylinders involves five steps: decoppering and dechroming, degreasing, copper plating, image transfer, and chrome plating [20].

The sensors in the automatic rotogravure machine are managed by a Programmable Logic Controller (PLC). The PLC generates a command signal that corresponds to the motion control of each motor when a command is delivered from the Human Machines Interface (HMI). Using motion commands and feedback signals, the PLC then manages each motor to regulate the web tension and speed, enabling the machine to function as required [21]. **Figure 2** depicts a schematic of the operation of a rotogravure machine using a roller-to-roller arrangement. The first, second, and third color printing procedures are carried out after the unwinding roll and before the infeed. A rotogravure machine allows for up to six or eight hues of coloring instead of just three. Following the completion of the color printing process, go on to the outfeed area, and ultimately, the rewinding roll.

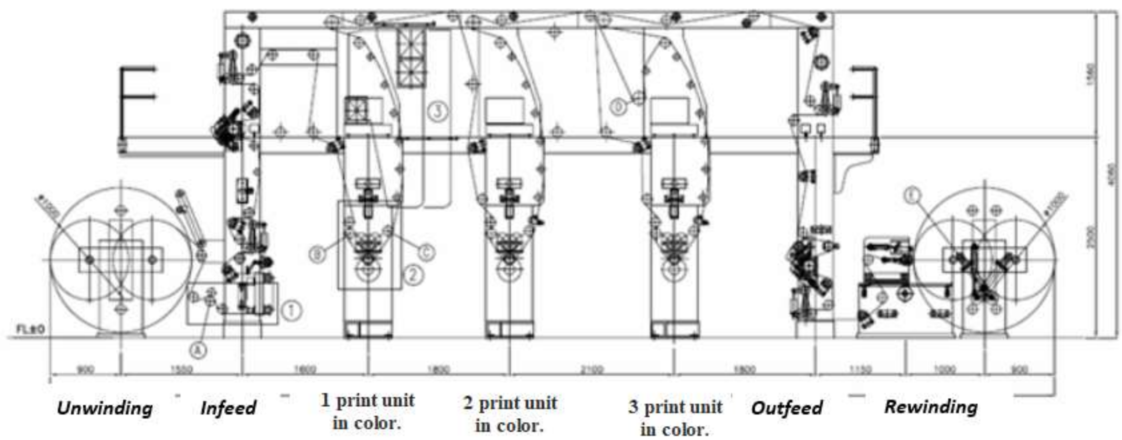

Figure 2. Schematic of the rotogravure machine work process [22].

3.2 Tension control

When referring to machinery, tension can be understood as tightness or tension in key machine components like belts, chains, or ropes. Incorrect tension applied to these parts can have an impact on how well a machine works and can damage or fail it. The substrate or printed material, which is caused by the roller to roller mechanism (R2R) and heat during drying, which creates changes in the material, is the tension control that is adjusted in production using a rotogravure machine.

The tension is often measured for monitoring rather than control in the printing section of the R2R printing system since tension control can result in register faults. However, to achieve high precision control, it is necessary to measure and regulate the tension in the R2R system in addition to controlling register error to generate an accurate print [23][24]. Research is being done on temperature and tension management for the rotogravure machine's usage of a shaftless engine for cylinder drive [13][15][25]. As a result of the machine's high speed and vibration, which makes the electronic component, notably the servo motor, prone to mistakes, using a machine without a gearshaft has less danger of inaccurate results. Additionally, compared to a machine with a gear shaft model for its cylinder drive, the control is more difficult.

A rotogravure machine has two mechanical mechanisms for winding rollers. The substrate material is stretched by the unwinding roller, which also serves that purpose, and pulled by the rewinder. **Figure 3** depicts the unwinding and rewinding mechanism [26][27][22]. The R2R system on the modified printing press consists of winding and rewinding, floating roller tension rod, primary drive guide roller, tension detector guide roller, and regular guide roller [28].

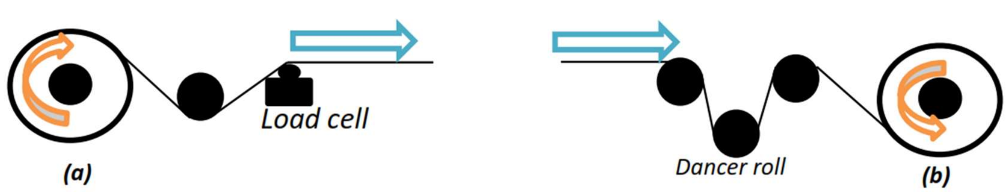

Figure 3. (a) unwinding and (b) rewinding

This can be accomplished with a roll-to-roll (R2R) printing method for rotogravure machines used in mass production with printing presses, thus extremely accurate web tension management is required to eliminate registration mistakes and maintain the thickness and roughness of the printing device within bounds. With the help of a loadcell (tension detector) and dancer system, the R2R system's web tension is controlled for printed applications using centralized multi-input-single-output (MISO) technology [29]. A computer is utilized to program the system when utilizing a PLC to regulate the tension on a rotogravure machine. To set the torque control on the servo motor, the sensor signal is translated from analog to digital as input and from digital to analog as output [30]. The benefit of PLC use is superior performance [31].

Calculating the torque value is necessary to determine the tension value. The force exerted on the rotating shaft is referred to as torque [32]. **Figure 4** the braking torque (T) on the weaker side determines the stress (f) that is delivered to the material in equation (1). The link between torque and tension is demonstrated in the statement below. f=tension, T=torque, D=diameter, and r=radius.

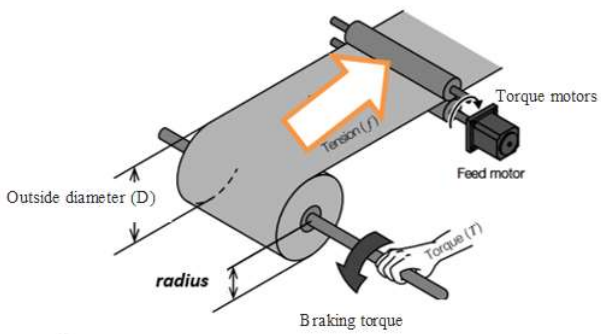

Figure 4. Illustrates how torque and tension are applied to a rotogravure machine

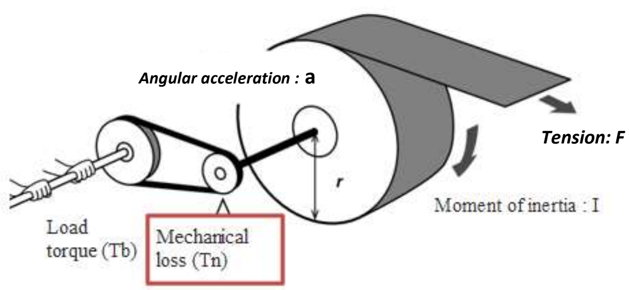

Figure 5. The force that causes tension in the machine

The force produced by the material's tension during printing is depicted in **Figure 5**. I x a is generated when the angular acceleration changes during acceleration or deceleration and has no effect when the speed is constant, according to **Figure 5**. Stress is produced by attraction F, moment of inertia I, and angular acceleration a. The mechanical losses produced when the bearings supporting the shaft and the belt gears are driven are what cause the frictional resistance Tn. Temperature and rotating speed both affect Tn. The bearing fluctuates in value by the gap precision. The load torque created by the brakes, etc., is denoted as Tb. These three torques must be correctly regulated if the tension is to be controlled. Equations (1) and (2) are used to determine the stress caused by the material printing process:

$$f = \frac{T}{D/2} \text{ or } \frac{Torque}{r} \quad (1)$$

$$F \times r = I \times a + Tn + Tb \quad (2)$$

The moment of inertia is a measure of how difficult it is for a rotating item to turn. When a force is applied, a mass in linear motion has trouble moving and stopping. When a force that causes rotation is applied, the moment of inertia in the rotational motion shows how difficult it is to turn and how difficult it is to stop. Large outer diameter or mass reel shafts are challenging to start rotating, but once they do, the shaft will naturally keep turning. The huge moment of inertia is another name for this. Equation (3) displays the moment of inertia, while equation (4) displays the torque caused by inertia;

$$I = \text{separation from the rotational center} \times \text{mass} \quad (3)$$

$$T = I \times a \tag{4}$$

When a rotating object is propelled by pulling on it, torque manifests as tension on the pull side (positive side) and as stress on the slack side (negative side) of the rotating object. Due to the fact that the angular acceleration during operation at constant speed is zero, no torque is produced.

3.2.1 Open loop tension control

The touch arm approach, the ultrasonic method, the integrated thickness detection method, and the sensorless method are the four techniques that can be utilized to create tension control with open loops. In the touch arm method, the lever movement detects the roll motion angle in contact with the roll diameter and produces a signal that is proportional to the roll diameter. Potentiometers and differential transformers are used as arm angle detecting sensors in this technique. Care must be taken to prevent touch from harming the material's surface. The pressing arm's pressure has to be adjusted. **Figure 6** depicts how the roll diameter detecting method is configured with the touch arm.

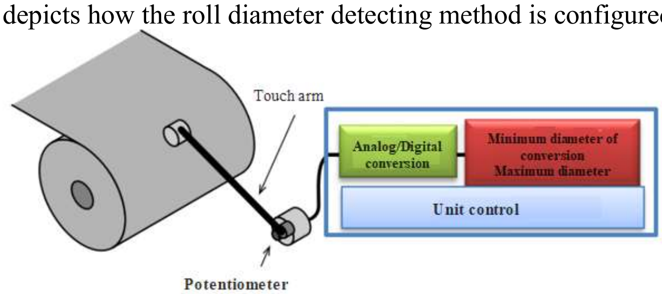

Figure 6. Touch arm configuration for unwinding diameter detection

In the ultrasonic approach, the roll diameter is determined when an ultrasonic sensor reads the signal returned by the reflection. Because no touch is necessary, this approach is distinguished by the fact that the material is not harmed. Ultrasonic sensors are unable to detect certain materials. The direction of the tension change does not match the direction of the winding diameter change. **Figure 7** depicts the ultrasonic technique arrangement.

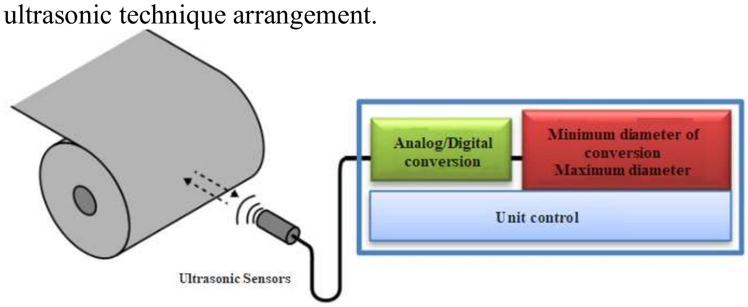

Figure 7. Ultrasonic technique configuration

In the integrated thickness detection method, the roll diameter is determined using the initial value, the roll shaft material thickness, and the rotational speed of the roll shaft as detected by the proximity switch coupled to the roll shaft. Utilizing the fact that the roll diameter changes twice as much as the material thickness each rotation of the roll shaft, this method calculates the cumulative thickness of the material with respect to the beginning value of the roll diameter. **Figure 8** illustrates how the integrated thickness-detecting approach is set up.

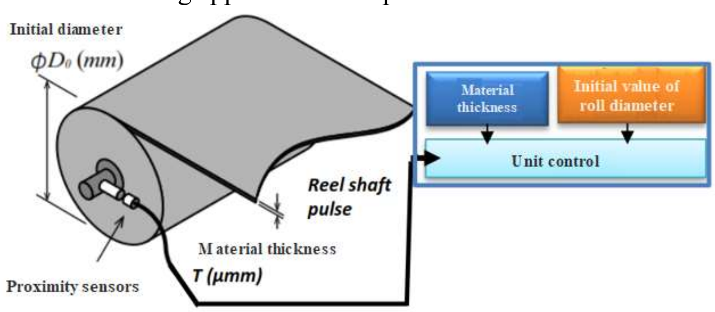

Figure 8. Integrated thickness-detecting method configuration

In the sensorless technique, the set value of the material thickness and the average speed value is used to determine the change in roll diameter according to the time interval. When materials with a thickness of T (μm) are rewinding and unwinding at a speed of V (m/min), the winding diameter is D (mm). Figure 9 depicts the sensorless technique arrangement.

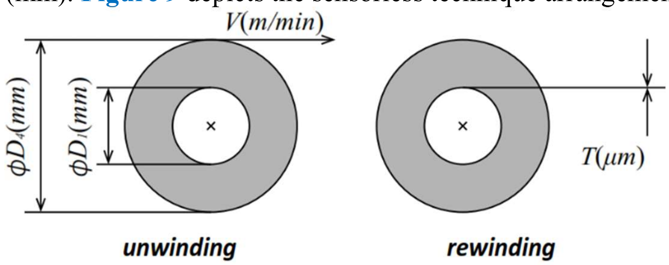

Figure 9. Sensorless approach configuration

Equation (5) is used to compute rewinding, whereas equation (6) is used to calculate unwinding, where D1 = lowest diameter, D4 = maximum diameter, and t = operation time.

$$D = \sqrt{D_1^2 + 4TV_{t/3,14}} \tag{5}$$

$$D = \sqrt{D_4^2 + 4TV_{t/3,14}} \tag{6}$$

The change in winding diameter D over time can be determined automatically using the formula t = operating time when the initial value of the minimum diameter D1 (for rewinding) or maximum diameter D4 (for unwinding) is set, together with the material thickness T and average speed V. The "speed and thickness setting method" is the name of this technique.

3.2.2 Closed-loop tension control

The material stress is directly monitored by the stress detector in the closed-loop control method, also known as the stress feedback method, and the monitored value is fed back to make it equal to the goal value for stress control. Even if the target tension is obtained accurately, short-term disruption events may nevertheless manifest. Integral proportional control can typically be used to get around this [33][34][35][36]. Feedback allows for greater tension precision than open loop control. Figure 10 depicts the closed-loop control arrangement.

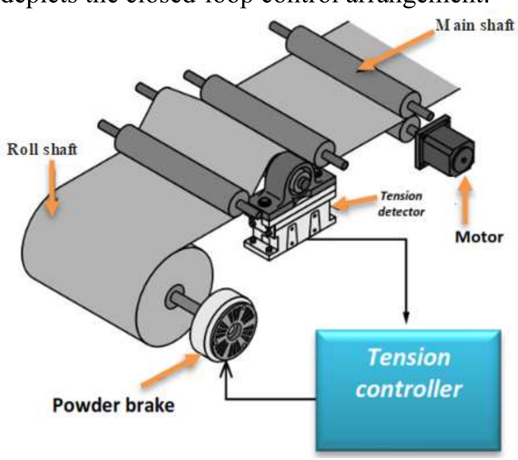

Figure 10. Closed-loop control configuration

The benefits of closed-loop control include high control accuracy, direct reading of the controlled tension, and more accurate actuator torque characteristics. The need to coordinate machine manipulation and control (more complex machines), the high initial investment, and the fact that control is susceptible to brief disruptions are all disadvantages. Calculating the torque on the roller is necessary when using a rotogravure machine with an intermediate shaft (roller) for tension management. Figure 11 shows the drive roller is displayed.

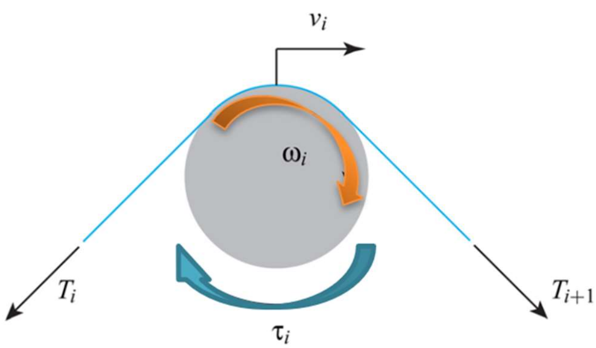

Figure 11. Drive roller

Equation (7) displays the governing equation for the i-th angular velocity [37], where τi is the torque applied by the motor on the roller shaft, *Ji* is the inertia of the roller, *τfi* is the friction torque, Ri is the radius of the roller.

$$J_i\ \omega_i = -\ \tau_{fi} + R_i\ (T_{i+1} - T_i) + \tau_i \quad (7)$$

3.3 Type of tension control system

Torque control for unwinding and rewinding is one of four types of tension control systems that can be used to manage the tension of printed materials on rotogravure machines. Speed control for rewinding and torque control for unwinding, speed control for unwinding and rewinding, and speed control for both. A device that coils and unwinds material is the simplest tension control method. In such a system, the towing side must regulate the speed of either the unwinding or the winding portion, while the other portion must be controlled independently. The system's main shaft is located on the towing side.

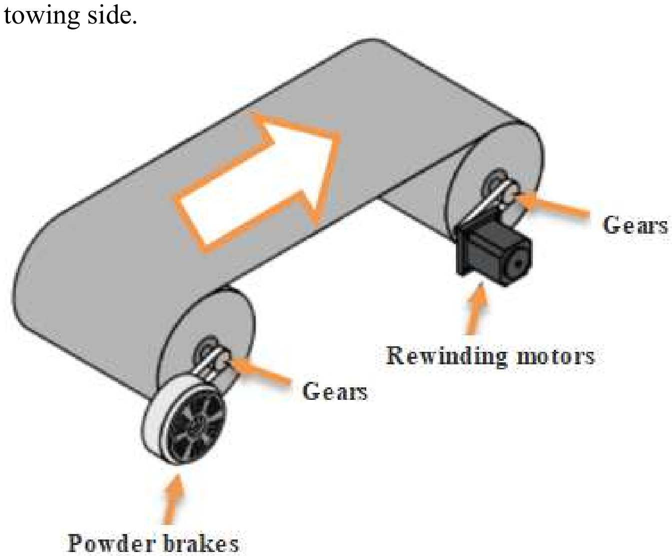

Figure 12. how a rotogravure machine's tension control is set up simply.

The powder brake in the system depicted in **Figure 12** controls the unwinding section. A torque control actuator, the powder brake can only function as a drag side. As a result, the tension in the discharge portion needs to be managed. However, the rewinding motor must regulate the speed such that the rolled material continues to move at the same rate even if the winding diameter varies. Torque or speed can be used to regulate the rewinding portion, which serves as the towing side. The tension from the unwinding portion to the rewinding section is decided by the outcomes of the unwinding control in the system, regardless of how many free rollers are set in the middle section. The material needs an intermediary shaft during the printing process in order to be appropriately regulated. The intermediate shaft keeps the printed material's tension in check. The benefits and drawbacks of using an intermediate shaft are listed in **Table 1.**

Table 1. Lists the benefits and drawbacks of adopting intermediate shafts.

Unwinding	Rewinding	Benefit	Losses
Torque Control	Torque Control	- The tension for the winding and the tension for the discharge can be controlled individually. - When dancing dolls are used, the technique can get around the material's low tension. - The dancer roll lessens the peaks and valleys of acceleration or deceleration.	- Each rewinding and unwinding main shaft needs an actuator. - Squeezed material has the potential to harm the material's surface.
Speed Control	Torque Control		
Torque Control	Speed Control		
Speed Control	Speed Control		

The unwinding roller shaft controls the unwinding roller shaft and the wound roller shaft by torque or speed in systems with an intermediate shaft, and the intermediate shaft controls by speed. **Figure 13** and **Figure 14** display four different combinations. Powder brakes, servo motors operating in torque control mode, inverters for motors with encoders, among other actuators, are used to control torque. Servo motors in speed control mode, motors and inverters without encoders, etc. are examples of actuators for speed control. When the motor is employed on the regenerative side (for braking), a separate regenerative unit is needed.

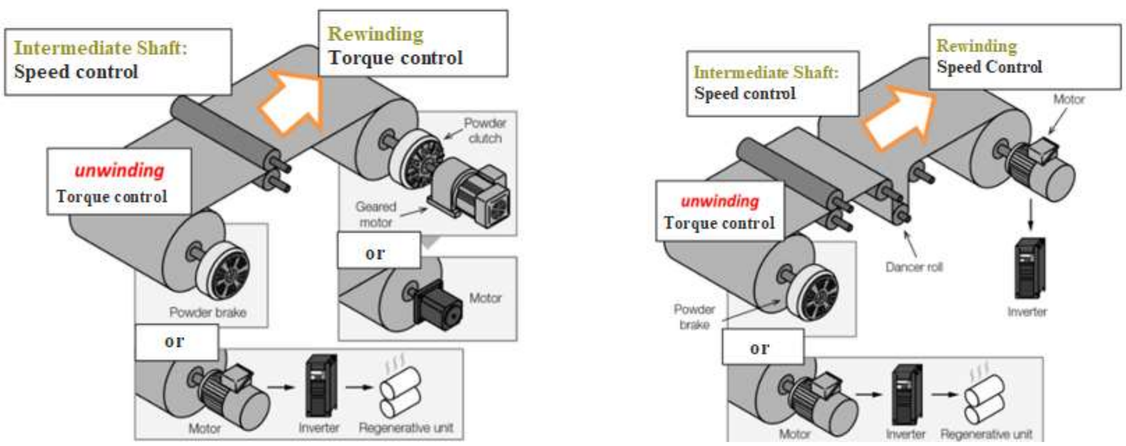

Figure 13. Torque control configurations for unwinding and rewinding (option 1) and speed control configurations for unwinding and rewinding (option 2)

The speed control configuration for unwinding and torque control for rewinding is shown in **Figure 14.**

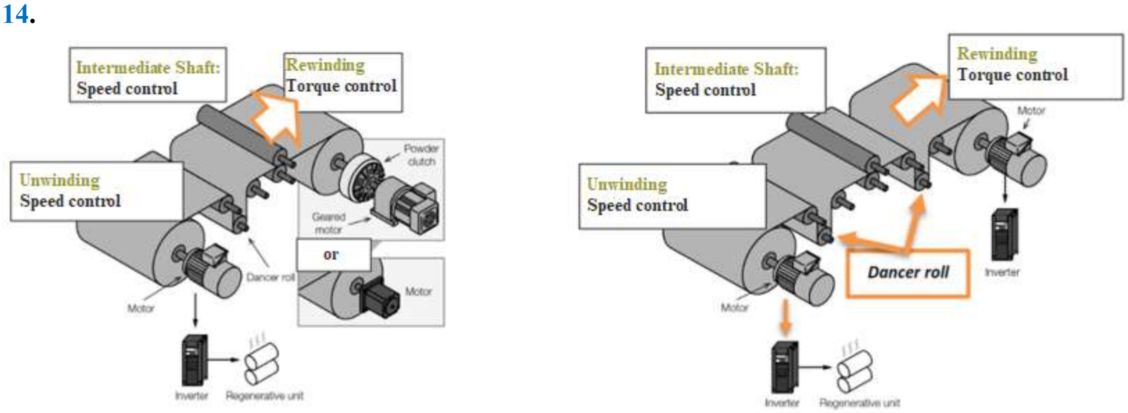

Figure 14. Depicts the arrangement of the speed control for unwinding and torque control for rewinding

When unwinding, a powder brake can be used to regulate torque at low speeds, while a motor can be used to control torque at high speeds. Powder brakes, servo motors operating in torque control mode, inverters, and motors with encoders are all employed by actuators for torque control. Servo motors, inverters, and motors without encoders are all used by actuators for speed control.

3.4 Rotogravure machine tension control system development

Figure 15 illustrates the development design and tension control system of a six-color automatic rotogravure machine based on the findings of a literature review.

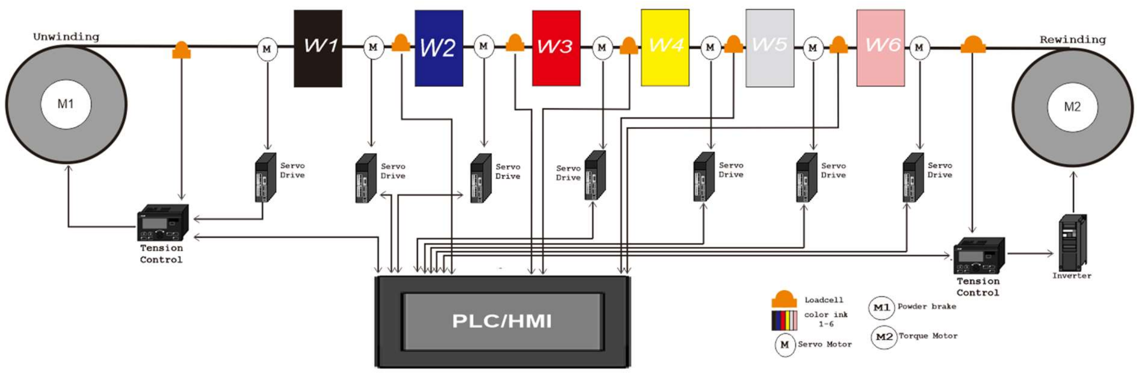

Figure 15. 6-color rotogravure machine tension control design

Six and eight color automatic rotogravure printers are available on the market. **Figure 15** depicts the design of a six-color automatic rotogravure machine with a tension control based on the previous description. To provide correct coloring and high-quality print output, the tension control is employed to modify the substrate. Up until the point of the rewinding procedure, the first coloring serves as a guide for subsequent colorings. To measure the stress on the printed material, the machine setup has a load cell (tension detector). When the substrate material deforms or stretches during the coloring and drying processes, a signal input from the sensor will be provided to the PLC or HMI to regulate and control the servo motor.

Creation of tension control applications that use speed and torque control during unwinding and rewinding, respectively. The sensor uses a load cell under PLC and HMI control. When rewinding a motor, actuators are used in the form of powder brakes, roll-to-roll settings on servo motors that use torque control, and motors and inverters fitted with encoders that use speed controllers.

4. CONCLUSION

Torque control for unwinding and speed control for rewinding can be used to provide tension control for rotogravure machines for six colors. The sensor uses a load cell under PLC and HMI control. When rewinding a motor, actuators are used in the form of powder brakes, roll-to-roll settings on servo motors use torque control, and motors and inverters are fitted with encoders that use speed controllers.

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