Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Efficiency and Precision in Printing: Study of the Control System of a Rotogravure Machine

Rizki Setiadi[1,*], Wirawan Sumbodo[1], Wahyu Caesarendra[2], Deni Fajar Fitriyana[1], Kriswanto[1], Aldias Bahatmaka[1]

[1] Mechanical Engineering study Program, Faculty of Engineering, Universitas Negeri Semarang, Semarang, Indonesia
[2] Faculty of Mechanical Engineering, Opole University of Technology, Poland

ARTICLE INFO

Article history:
Received 3 October 2024
Received in revised form 4 November 2024
Accepted 10 November 2024
Available online 30 November 2024

Keywords:
Precision; printing machine; control system; rotogravure machine

ABSTRACT

Rotogravure printing is a well-liked and effective printing technique in the packaging sector of a printing cylinder. In making an automatic rotogravure machine, it is necessary to design an appropriate control system. In Indonesia, semi-automatic technology is still used to make rotogravure machines, and printing speeds are often slow. For automation machines, they are still imported. Apart from that, the machine's ability to adjust its precision is also limited. The purpose of this article is to examine the control system for a 6-cylinder automatic rotogravure machine and discuss the rotogravure machine printing process, important aspects of rotogravure machine operation, differentiation in selecting motor types for torque and speed control, as well as advantages in efficiency and precision control over the environment. The method of using a literature review is qualitative-descriptive. The main findings on rotogravure machines include five main aspects: (1) ink flow management, (2) control of the drying system, (3) register control, (4) tension and speed control, and (5) fault detection, data logging, and analysis.

1. Introduction

Due to falling transit and communication costs, as well as quicker product movement, the industrial sector is currently facing greater international competition [1]. The pursuit of accuracy and efficiency in printing technology is crucial to satisfying the expectations of an industry that is constantly expanding. Rotogravure printing stands out among the numerous printing techniques as a top-notch and adaptable technique frequently used to make packaging goods, labels, magazines, and much more. A sophisticated control system that allows seamless execution of complicated designs and consistently high-quality output is at the core of this cutting-edge printing technology.

Popular Printing Techniques for Various Packaging. There are several options for selecting the printing technique that will work best for your brand. The most widely used technologies recently:

* *Corresponding author.*
E-mail address: rizkisetiadi@mail.unnes.ac.id

https://doi.org/10.37934/aram.128.1.1123

i. Offset printing: Using metal plates, the pattern is transferred or "off-set" onto a rubber roller before being transferred to the printing medium.
ii. Screen printing mesh screens, which are appropriate for bulk printing, press the inks and transfer the picture to the chosen material, such as cloth.
iii. Digital printing: Digital printing uses digital designs rather than printing plates and offers a quick turnaround. Inkjet printers transfer ink.
iv. Rotogravure printing: This intaglio printing method entails laser engraving the desired design onto a steel cylinder that has been coated with copper. It entails etching the picture on the cylinder and pressing the image onto the substrate to transfer it.
v. Flexible printing: The printing plates are affixed to elevated, rotating cylinders, much like letterpress printing. It is a type of printing technique that makes use of a flexible relief plate. Additionally, the necessary images are printed on the material using quick-drying inks.

The printing and packaging industries are constantly under price pressure. Despite being commonly regarded as the printing technology that provides the greatest and most consistent print quality at high speeds, gravure printing on the other hand has disadvantage due to its expensive setup costs. Gravure printers must continually improve their technology and lower the prices of their manufacturing processes to maintain their competitiveness, especially in the flexible packaging market where flexographic printing has become quite powerful over time.

Numerous manufacturing sectors have adopted automation technology in the fourth industrial revolution [2]. Technology known as automation involves the use of computers, electronics, control systems, and machines. The production process can be managed by automation systems. Automation may speed up a production process and boost output. 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. A packaging printing machine is required as a result.

The printing device's capacity and output speed determine its final product. The structure of contemporary printing machines is extremely complex and includes several control mechanisms [3]. Because printing is such a dynamic and creative process, printing technology has advanced significantly in the area of automation [4]. A rotogravure printer is the type of printing device used in industry for packaging printing. In Indonesia, semi-automatic technology is still used to create rotogravure machines, and printing speeds are often slow. Additionally, the machine's ability to manage its precision is likewise restricted.

A rotogravure machine is a printing device that is typically used to print flexible materials for packaging, including metal, paper, and plastic [5]. The rotogravure printer offers benefits including quick printing, vibrant color, large print areas, thick ink layers, good dot reproducibility, and stable quality. Several control methods are supported in an automatic rotogravure machine, including tension, color control (register control), and temperature control for drying after printing. The technology used in gravure printing machines for tension control is crucial. A crucial element in ensuring printing quality is stable printing tension [6].

The rotogravure method is a direct transfer technique for printing onto wood-pulp fiber-based, synthetic, or laminated substrates, such as Papers, Carton board, Aluminum foil, and Films such as polyester, oriented polypropylene (OPP), nylon, and Polyethylene (PE). The rotogravure printing process is shown in Figure 1.

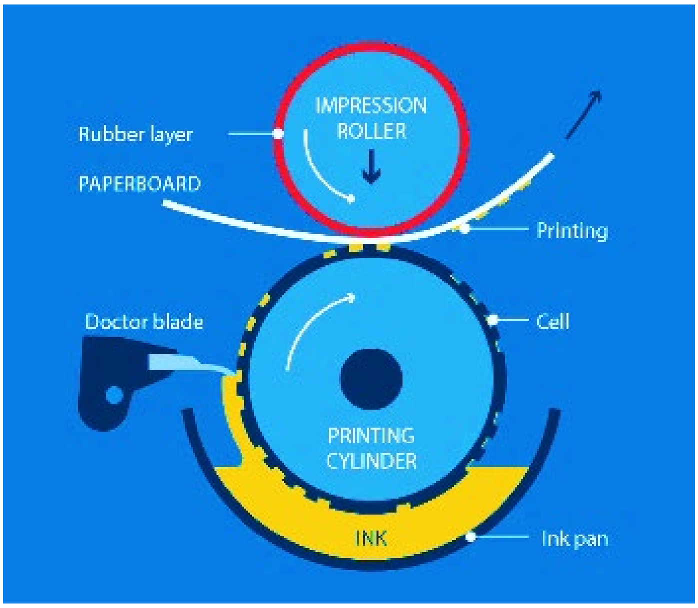

Fig. 1. The printing process used rotogravure [7,8]

According to Figure 1, the material to be printed (substrate) in a rotogravure machine is clamped between two cylindrical rolls, namely the impression rolls and the printing cylinder. In the rotogravure cylinder, there is a cavity pattern of cavities known as "cells" on the surface. The engraving or etching system determines how the gravure cylinder surface is different. Either copper or zinc, protected by a final chrome finish, can be used for the surface. The cells absorb ink as the cylinder rotates through an ink pan. Before the ink is transmitted directly to the paperboard surface, the surplus ink on non-image areas is scraped off the cylinder by a doctor's blade. The foundation for the inks is either water or low-viscosity solvents. High-velocity air nozzle dryers in hoods that are either heated or heated and cooled are used to dry the ink after each ink unit [7].

Based on collaboration with industrial partner CV Surya Cipta Inti Pratama, Semarang Indonesia, the problem is that currently no industry produces automatic rotogravure machines. Most machines are still imported. Currently the machines produced are semi-automatic machines. To design an efficient and precise 6-color automatic machine, this article discusses initial studies and analysis regarding efficiency and precision to preserve the environment. Table 1 is a general description of many rotogravure machines that have been made by industry. Table 2 shows the design for an automatic 6-color rotogravure machine.

Table 1
General specification rotogravure printing machine [9]

Substrate	PET, BOPP, CPP, LDPE, nylon, alu-foil, paper
Web width	600 mm-1600 mm
Cylinder circumference	350 mm-900 mm
Number of colors	1-12 colors
Line speed	100 m/min-350 m/min
Drive type	Mechanical line shaft or electronic line shaft
Drying source	Electric heater / gas burner / thermic fluid / steam
Unwind diameter	⌀ 600-⌀1000 mm
Rewind diameter	⌀ 600-⌀1000 mm

Table 2
Design for an automatic rotogravure

Dimension (width x height x length)	1800 mm, 2300 mm, 11000 mm
Cylinder circumference	800 mm
Number of colors	6-colors
Line speed	Max. 150 m/min
Drive type	Mechanical line shaft
Drying source	Electric heater
Unwind diameter	Max. 900 mm
Rewind diameter	Max. 900 mm
Gearbox	Direct gear, M3

2. Methodology

This article is qualitative descriptive. The data was collected by reference to journals about rotogravure, control systems, and servo motor operation user manuals. Descriptive analysis is used to describe efficiency and precision, important aspects of the efficiency and precision of rotogravure machines, as well as their impact on the environment.

3. Results

3.1 Efficiency and Precision in Printing

An important aspect of rotogravure machine operation is printing accuracy and efficiency. Packaging, labels, and decorative printing are just a few examples of the many uses for the high-speed, high-quality printing process known as rotogravure printing. A rotogravure machine's control system is essential for obtaining the necessary level of accuracy and efficiency. Here is an analysis of a rotogravure machine's control system to see how it affects productivity and accuracy. In this article, we find five main aspects of supporting efficiency and precision on rotogravure machines. These five aspects are important for automation design on rotogravure machines to reduce waste and reduce electrical energy consumption:

i. Ink flow management, ink viscosity control, and colour management: Accurate printing depends on effective ink flow management. The gravure cylinders' ink supply should be controlled by the control system, resulting in uniform ink coverage on the substrate. The viscosity of the ink can impact the caliber of the printed image. To maintain consistent print results, the control system may have systems for monitoring and adjusting ink viscosity. The control system may include colour management capabilities to guarantee that the ink colors fit the desired requirements for accurate color reproduction.
ii. Control of the drying system: Quick drying and ink smearing can both be avoided with careful drying. To get the best outcomes, the control system controls the temperature, air velocity, and conveyor speed in the drying area. The efficiency of drying printed materials will reduce electrical energy consumption, thereby reducing electricity use and production costs.
iii. Register control: Precise registration is necessary for printing in several colors. Each color layer is exactly aligned with the one before it thanks to the control system's usage of sensors and actuators, which also helps to prevent color shifting.
iv. Tension and speed control: It's essential to maintain the substrate's proper tension to avoid wrinkles and guarantee precise printing. The control system accounts for changes in roll diameter and machine speed when adjusting the tension in real-time. Consistent

machine speed is necessary for both efficiency and accuracy. To ensure that the substrate travels through the machine at a steady rate, the control system monitors and modifies the speed.

v. Fault detection, data logging, and analysis: For the control system to be effective, it must be able to identify defects and errors in real-time. To reduce production hiccups, it can activate alarms, pause the machine, or make automatic adjustments. Data collected on machine performance, including print speed, registration accuracy, and ink usage, can be used to gradually improve the printing procedure. This information can be stored in the control system for analysis and process optimization.

Figure 2 describes the products printed using a rotogravure machine. The printed products produced include flexible food packaging, shrink labels, PE shopping bags, foil (Pharmaceutical), food and lidding, in molding labeling, paper, etc. Figure 2 shows that most substrates from rotogravure machines are materials that are difficult to decompose as waste. Apart from that, if it is recycled it will also have an impact on increasing electrical energy consumption.

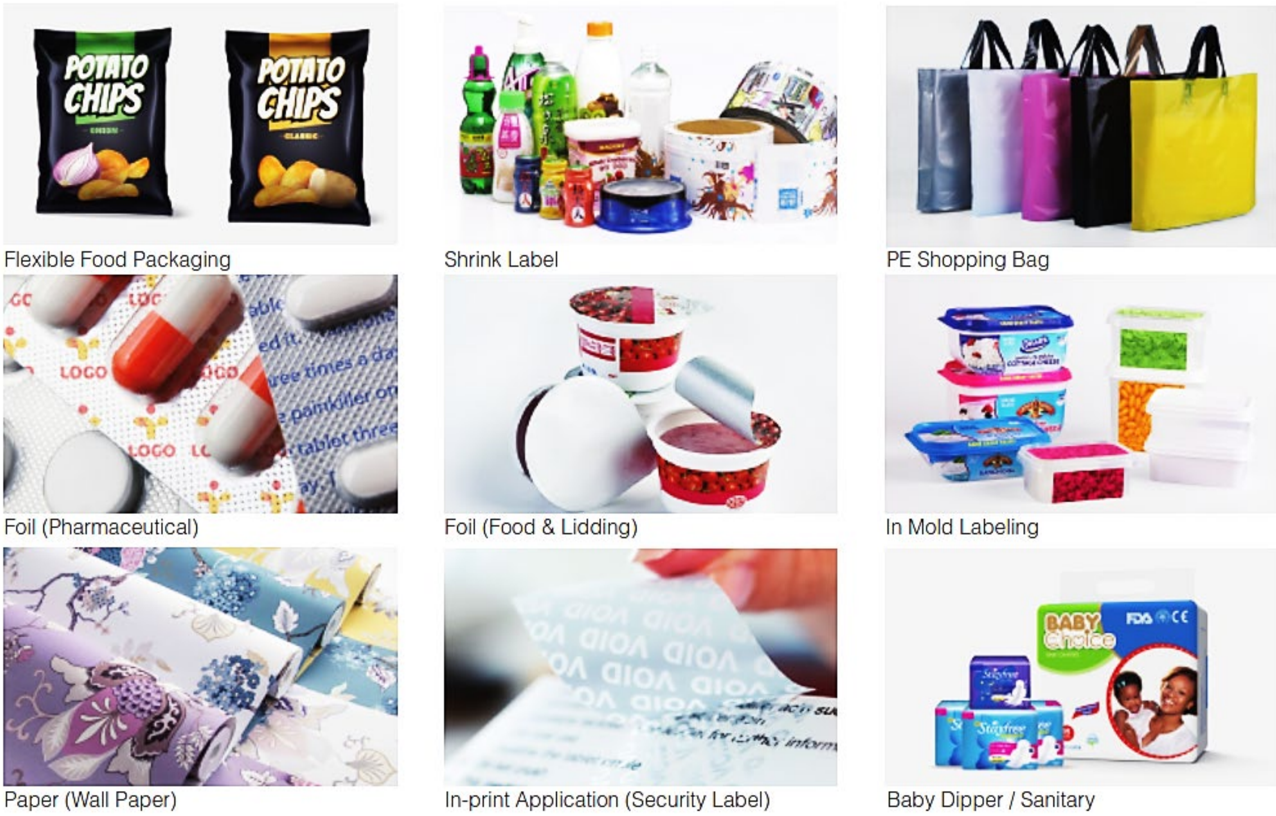

Fig. 2. Product list rotogravure printing machine [9]

3.1.1 Ink flow management

The following is an analysis of how the viscosities of gravure ink affect optical print quality: (i) The ink density curve varies depending on the viscosity value, and while it is generally better with higher densities, it does not necessarily rise as viscosity increases (more seconds per unit volume). Although density can drop as it reaches a saturation point, the value of density does not necessarily rise as viscosity does. The ideal viscosity to choose for black ink is 25 seconds. (ii) Regardless of the ink's viscosity, which ranges from 16 seconds to 30 seconds, the contrast properties are not improved. However, the contrast is best for ink viscosity between 22 and 25 seconds. (iii) According to an objective investigation, increasing ink viscosity led to darker-looking prints and mottling issues. (iv) In terms of the dot structure analysis, it can be said that the dots get rounder, sharper, and darker as the viscosity rises. The low-viscosity and high-viscosity experiments' dots both showed issues such as spreading, missing dots, and doughnuts. For the color black, the best dot structure was seen between 22 and 25 seconds [10].

For the quality of the finished print, the doctor blade wipe's effectiveness and precision are essential. The blade holder works shown in Figure 3. The majority of gravure presses use positive doctoring, which involves positioning the blade at an acute angle to the gravure cylinder while rotating the press. It is thought that the ideal angle is between 65° and 75° [11]. The blade-holding idea comes into play here. This idea is based on lamella technology but advances the development by lowering the cost of the blade and concurrently shortening the handling time, which leads to real operating cost reductions. There are three essential parts to the blade holder shown in Figure 4.

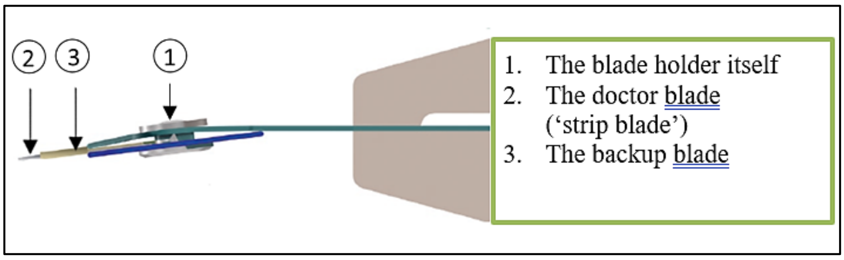

Fig. 3. The blade holder works [11]

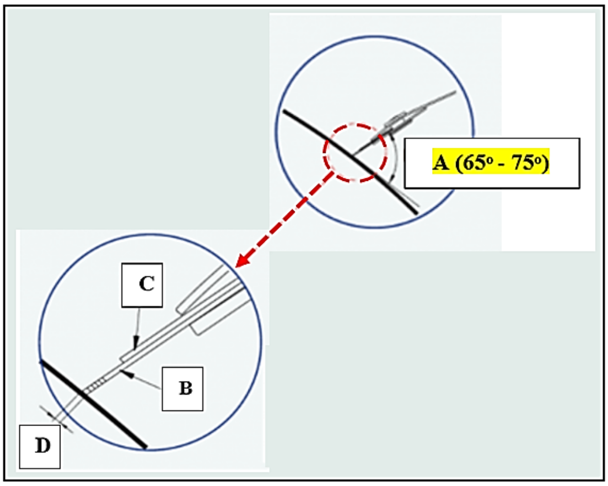

Fig. 4. Blade holder configuration at the rotogravure cylinder [11]

Figure 4 shows a magnified view of an AkeBoose blade holder. Angle (A) at 65o to 75 o for optimal contact between the blade tip and cylinder. Greatly magnified view of doctor blade (B) and backup blade (C) in contact with the cylinder. Width D: contact area between blade and gravure cylinder. The backup blade, which is only 8.0, 8.5, or 9.0 mm wide, supports the strip blade to mimic the lamella and provide the required stability. Instead of the wide lamella doctor blades, both of these blades are set in the blade holder, which is a permanent fixture in the machine holder. The machine holder in the press does not need to be mechanically adjusted. The operator can customize the design and quality of the lamella tip thanks to the width of the backup blade and the various doctoring strip blade thickness options. There is no other place in the industry where doctors can be as flexible as they are here. Similar to the standard wide lamella blade, the strip blade measures roughly 2 mm in thickness. About 2 mm of the stripping blade in the blade holder is utilized during printing, just like the typical wide lamella blade. A 10 mm strip blade is far less expensive than a 60 mm wide precisely ground lamella doctor blade when looking at blade cost per meter.

Ink flow control that is efficient is essential for accurate printing. The gravure cylinder's ink supply needs to be managed by a control system to ensure that the media is covered evenly. The method of placing a variety of thin layers of functional materials (ink) on a reasonably priced substrate that may be recycled and or naturally destroyed in the environment results in printed electronics. The manufacturing process, then, is divided into three complementary stages: choosing the material, printing, and post-processing [12]. Inks having conductive, semiconductor, or dielectric properties, as well as substrates made from synthetic or natural polymers, are the main components of printed electronics materials. In the case of contact printing, the ink is transferred to the substrate together with the master through direct touch, whereas the ink is typically deposited onto the substrate [13,14].

3.1.2 Drying system

Binder, pigment or dissolved dye, and a solvent as an organic solvent that is volatile or airborne make up the major components of printing ink. Before moving to another media, the ink must be able to wet and remain liquid. The ink must dry after entering the medium, which calls for as quick a solidification as possible that is at least damage-resistant. To prevent drying of the printing machine during printing machine operation or brief downtime, the ink printing structure must be able to dry fast and adhere to the substrate after printing and drying. For printing inks, different drying processes exist, and they may be influenced by the following elements [15]:

i. Printing technique.
ii. The type of printing ink (liquid, paste, soluble in water or an organic solvent, cured by radiation, etc.
iii. Printing equipment velocity.
iv. Printing substrate material.
v. The type of printed product (commercial printing, package printing, etc.).
vi. Characteristics of the drying system.

The schematic design of the dryer is shown in Figure 5. In the drying control, a thermocouple can be used as a temperature sensor. Thermocouples are common devices and are widely used in many industrial applications as temperature gauges [16]. For the dryer for each coloring, a 750-watt electric heat barrier and a 500-watt blower are used. The dryer design was modified based on semi-automatic machine production and the research of Park *et al.,* [17].

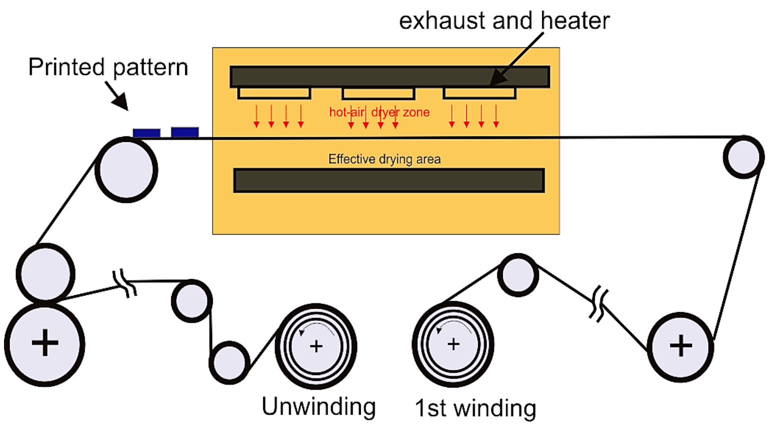

Fig. 5. The schematic of the dryer

3.1.2.1 Absorption drying

The main method of ink drying for gravure, flexography, and web offset is evaporation. Heat-setting inks are dried by evaporation in a hot air dryer while non-rubber-based sheet-fed offset inks are cured via oxidation polymerization. To complete the drying of the film ink, it is also possible to combine two or more drying systems. Ink is dried by absorption when printing is completed on an absorbent surface such as printed newspaper or crumpled board [18]. The ink structure is obtained mainly by the penetration of the liquid component into the substrate and sucked into the paper through the paper-translucent tube, leaving the dry ink on the surface. Generally, this type of drying method depends on the viscosity of the printing ink carrier, the carrier material (binder), and the absorption capacity of the substrate [19].

3.1.2.2 Absorption drying

The Oxidation Polymerization type of drying system relies on a chemical reaction between oxygen from the atmosphere and a drying oil (such as linseed oil, china wood oil, or soybean oil) within the vehicle system components. The result of this process is changing the ink layer on the substrate into a semi-solid or solid. The mechanism of oxidation polymerization is carried out as follows:

i. Oxygen in the air adds to the double bonds of drying oil molecules to form hydroperoxides.
ii. In the presence of an initiator or catalyst (cobalt or manganese salt), hydroperoxide forms very reactive free radicals, attack other molecules and attach to form new (large) free radicals, this causes polymerization.
iii. Since many molecules have many reactive sites (i.e. double bonds), some cross-links are formed thereby forming a network and then the ink layer is dried after a few hours.

3.1.2.3 Evaporation drying

Evaporation drying mechanisms are used in several printing methods for example web offset (high boiling point mineral oil inks) and flexographic and gravure printing (low boiling point organic solvent inks), With increased efficiency the drying process must be combined with other drying mechanisms such as IR heaters for heating Wet the ink first before putting it in the drying chamber. However, the evaporation drying method still has several obstacles such as:

i. Organic solvent-based inks require high capital investment in accessory equipment for pollution control. Waste air from the dryer exhaust containing organic vapors must be cleaned before being discharged to the atmosphere.
ii. Water-based inks still use alcohol to improve the wetting and drying properties of the ink. Pollution control devices may still be necessary especially if ammonia and amine groups are present in the ink.
iii. Drying water-based ink using the evaporation method takes longer because the drying is 4.5 times slower than solvent-based ink.
iv. Higher energy costs.
v. Water-based ink drying systems require a large enough space to achieve complete drying; The paper web should remain in the drying area for 0.8 to 1 second. If the paper web moves at a speed of 8 m/s, the length of the dryer must be at least 8 m.

vi. The possibility of overheating (cooking) of the printing network due to loss of moisture from non-printing areas of the paper substrate can cause register inaccuracies and variations in visco-elastic properties of the plastic substrate. So, the printing and finishing process becomes increasingly difficult.

3.1.3 Register control

Rotogravure machines produce a lot of printing every day. During start-up and production, incorrect registration can result in the loss of several kilos of expensive substrate. To monitor the printing website for registration errors, the operator must post each printing. Printers and converters require solutions that automatically control registration during the printing process, thereby minimizing rejects and increasing throughput. Proper registration is required for printing in some colors. Each color layer is aligned exactly with the previous layer thanks to the use of sensors and actuators in the control system, which also helps prevent color changes. Gravure cylinders with the printing pattern inscribed on their surface were initially mechanically synchronized in rotogravure printing machines as well [20]. The cylinders can be linked directly to the motor in such rotogravure printing machines, reducing backlash. The alignment of a single-color print is achieved with outstanding register stability as a result of the high rotational stability and minimal printing position movement caused by this. Figure 6 shows that control register errors will cause the image quality to be inaccurate and blurry.

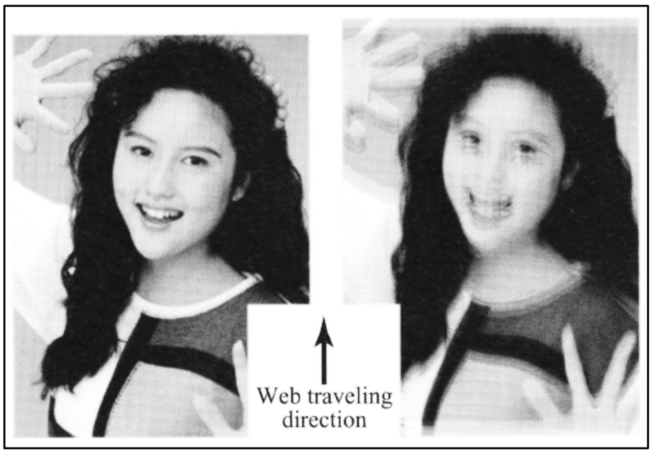

Fig. 6. Image with register error [21]

3.1.4 Tension and sped control

In order to prevent wrinkling and ensure accurate printing, it is crucial to maintain optimum media tension. When adjusting tension in real-time, the control system takes variations in roll diameter and machine speed into consideration. Tension is typically measured for monitoring rather than control in the printing portion of traditional R2R printing systems since manipulating voltage can result in register faults [22]. The voltage in the R2R e-Printing system must be adjusted and measured for high precision control, though, to provide more accurate register error correction. In a typical R2R system, the load cell can be used to detect tension. However, adding a load cell to an R2R system adds to the system's financial burden. The use of a machine without a gear shaft carries a lower chance of erroneous results due to the high speed and vibration of the machine, which makes the electronic components, notably the servo motor, prone to error. Additionally, control is more challenging compared to engines with a gear shaft type for operating the cylinder. Two mechanical systems rotate the rollers on rotogravure machines. A release roller that also has this function stretches the substrate material, which is then drawn by a rewinder. Winding and rewinding, a floating roller tension rod, a primary drive guide roller, a tension detector guide roller, and a regular guide roller make up the R2R system of the redesigned printing machine [22-24].

To control the speed of a rotogravure machine, servo motor control is needed for the machining process to run with precise results. A system made of servo drives and servomotors regulates closed-loop motor activity. The servomotor's actual position, speed, or torque is supplied back so that the command value can be compared with it and the subsequent errors between them can be calculated. To ensure that the system can deliver the appropriate performance, the servo drive then uses this error information to rectify the servomotor's operation in real-time. Closed-loop control is the term used to describe this feedback, error detection, and repair cycle.

To operate rotogravure machines with accuracy and precision, input for automatic rotogravure machines comes from sensors. Loadcell sensors are employed in the regulation of torque and speed. A temperature sensor is incorporated into the dryer control system. For measuring force, load cells are utilized a lot. Flexible load-bearing components or component combinations are used by many load cells. The auxiliary sensor detects the flexing of the elastic element brought on by the force applied to it and transforms it into a quantifiable output. The output can take the form of mechanical indications like verification rings and spring scales or electrical signals like those produced by strain gauges and LVDT-type load cells. The basic component of all regularly used load cells is this type of transducer, often known as an elastic device [25].

The sensor used for register control is a photo sensor. A photoelectric sensor is another type of position-sensing device. Photoelectric sensors, similar to the ones shown below, use a modulated light beam that is either broken or reflected by the target. As they provide a significant alternative for problem-solving in the industrial sensor industry, photoelectric sensors are widely utilized in the industrial production sector. With the advancement of photoelectric technology, sensors can now detect objects with a diameter of less than 1 mm. In addition to noticing the targets, photoelectric sensors also take note of variations in grounding conditions and other articles by various collections of visual qualities [26].

The main actuator in the rotogravure machine control system is the servo motor. These premium motors tend to be more compact and smaller, which is one of its characteristics. The task of increasing the efficiency of ever-smaller motors calls for continuous innovation in rotor, winding, stator, and housing designs. The servo motor that has been applied to the 6-color rotogravure machine is 11-15 kW [27]. We can use PID control for both position and speed for precise results to control the servo motor. Table 3 is a comparison of the use of servo motors of different brands, where there is no significant difference in electrical energy consumption and tends to be the same.

Table 3
Comparison of electric motor specifications for rotogravure control [28,29]

Data	Servo motor (Mitsubishi)	Servo motor (Omron)
Servo motor model	HF-JP 11K1M4	G-5 Series R88M-K11K015C
Rated output (kW)	11	11
Rated torque (Nm)	70	70
Maximum torque (Nm)	210	175
Power rate (kW/s)	223	223
Rated speed (RPM)	1500	1500
Rated current (A (RMS))	32	27.1
Input power (VAC)	400	400
Weight (kg)	74	58.9

3.1.5 Fault detection, data logging, and analysis

Fault detection is the process of finding an occurrence of a fault in a unit of the monitored process based on measurements that are provided by the system. Those faults lead to abnormal or system-critical behaviour of the machine, reducing the performance of the whole system significantly [30]. Logging is the process of gathering, analyzing, and storing data for use in the future. It is a procedure to use a system or a product to record events that occur during a test or measurement. The best data-logging mechanism is unquestionably the human brain and its memory, a creation of nature. Data loggers may be used to capture information when it needs to be gathered more quickly than a human brain can process it and when accuracy is crucial. Data logging denotes the management of a sensor's data collection and analysis processes [31].

The goal of a maintenance process is to preserve and keep industrial machinery in a state of full efficiency. Mechanical failures are examined, and the most widely applied algorithms based on machine learning are analyzed: Support Vector Machine (SVM) [32], Artificial Neural Network (ANN), Convolutional Neural Network (CNN) [33], Recurrent Neural Network (RNN) applications, and Deep Generative Systems. The strengths performance of different Machine Learning-based models for fault diagnosis namely: Support Vector Machine (SVM) has high accuracy, and low storage. Artificial Neural Network (ANN) has high accuracy, and fault tolerance. Convolutional Neural Network (CNN) is Feature extraction free, and efficient for big data. Recurrent Neural Network (RNN) is Robust to input size, short memory problem-free. Deep Generative Systems (DGM) is Complex structure detection and, generalized training [34].

Minimizing the impact of industry on the natural environment by developing modern assembly lines that are effective—both in terms of materials and energy—to increase production efficiency while minimizing costs [35]. Efficiency and precision in printing have two main advantages, namely (i) reducing waste and (ii) the consumption of electrical energy produced is also more efficient. In detail, it is described as follows:

i. There is less material wasted during pre-operation or initial setting of the machine, so that the waste produced is minimal, because most printed products use materials that are difficult to decompose and tend to damage the environment. The use of unused substrate can be recycled, but it requires energy consumption which will also have an impact on the environment if the electricity produced still uses coal.
ii. The consumption of electrical energy produced is also more efficient. By making more precise components, production equipment is used less, thereby reducing the use of electrical energy for the machining process of making components. Apart from that, printing efficiency and faster control also reduce electrical energy consumption, especially in electric motors and dryers. Having efficient and precise control will have an impact on reducing waste and energy consumption, thereby reducing negative impacts on the environment.

4. Conclusions

Based on studies that have been carried out, there are five main controls on rotogravure machines for efficiency and precision, namely:

i. Ink flow management, ink viscosity control, and colour management: In the ink management aspect, set the doctor blade angle between 65° and 75°.

ii. Control of the drying system: The efficiency of drying mold materials will reduce electrical energy consumption, thereby reducing electricity use and production costs.
iii. Register control: Register control errors will result in wasted printed material. With good register control, efficiency and precision in printing results will reduce waste.
iv. Tension and speed control: For speed and torque control on servo motors as the main movers in molds, there is no significant difference in power consumption when determining the motor brand, however, in terms of price, Omron motors are more economical compared to Mitsubishi. Control operations can use PID control.
v. Fault detection, data logging, and analysis: Failure mode and effect analysis (FMEA) is a method to support experts in their decision-making regarding machine risks.

Acknowledgment
This research/project was not funded by any grant.

References
[1] Schmidt, Daniel, Roman Gevers, Jörg Schwiep, Joaquín Ordieres-Meré, and Javier Villalba-Diez. "Deep learning enabling quality improvement in rotogravure manufacturing." *Procedia Manufacturing* 51 (2020): 330-336. https://doi.org/10.1016/j.promfg.2020.10.047
[2] Da Costa, Cesar, Cleiton Mendes, and Raphael Osaki. "Industry 4.0 in automated production." *IEEE* 19 (2017): 1-16.
[3] Kulachenko, Artem. "Mechanics of paper webs in printing press applications." PhD diss., KTH, 2006.
[4] Kataka, Moses B., Jean B. Byiringiro, and Peter N. Muchiri. "Optimization of printing press operations." *IOSR Journal of Mechanical and Civil Engineering* 15, no. 2 (2018): 53-63. https://doi.org/10.9790/1684-1502035363
[5] Emra, Devianita. "Usulan perbaikan waktu setup press roll untuk meningkatkan output mesin printing di Pt. Abc." *Jurnal Baut dan Manufaktur: Jurnal Keilmuan Teknik Mesin dan Teknik Industri* 2, no. 1 (2020): 17-23. https://doi.org/10.34005/bautdanmanufaktur.v2i1.959
[6] Shao, Ming-yue, Ji-mei Wu, Yan Wang, Kai Fang, and Xu-xia Guo. "Research on modeling method of winding tension system for gravure printing machine." In *2016 Symposium on Piezoelectricity, Acoustic Waves, and Device Applications (SPAWDA)*, p. 110-114. IEEE, 2016. https://doi.org/10.1109/SPAWDA.2016.7829967
[7] Grau, Gerd, Jialiang Cen, Hongki Kang, Rungrot Kitsomboonloha, William J. Scheideler, and Vivek Subramanian. "Gravure-printed electronics: recent progress in tooling development, understanding of printing physics, and realization of printed devices." *Flexible and Printed Electronics* 1, no. 2 (2016): 023002. https://doi.org/10.1088/2058-8585/1/2/023002
[8] Saengchairat, Nitipon, Tuan Tran, and Chee-Kai Chua. "A review: Additive manufacturing for active electronic components." *Virtual and Physical Prototyping* 12, no. 1 (2017): 31-46. https://doi.org/10.1080/17452759.2016.1253181
[9] http://www.symold.ecatalog.tw/data/308/11.pdf
[10] Kader, Abdel, and Magdy Ezzat. "The impact of ink viscosity on the enhancement of rotogravure optical print quality." *International Design Journal* 7, no. 1 (2017): 103-107. https://doi.org/10.12816/0049413
[11] AkeBoose GmbH. "Gravure blade holders: An approch to increased process flexibility and reduced operating cost in rotogravure printing." 2020.
[12] Wiklund, Jenny, Alp Karakoç, Toni Palko, Hüseyin Yiğitler, Kalle Ruttik, Riku Jäntti, and Jouni Paltakari. "A review on printed electronics: fabrication methods, inks, substrates, applications and environmental impacts." *Journal of Manufacturing and Materials Processing* 5, no. 3 (2021): 89. https://doi.org/10.3390/jmmp5030089
[13] Tiara, A. M., Hyeokgyun Moon, Gyoujin Cho, and Jinkee Lee. "Fully roll-to-roll gravure printed electronics: Challenges and the way to integrating logic gates." *Japanese Journal of Applied Physics* 61, no. SE (2022): SE0802. https://doi.org/10.35848/1347-4065/ac575e
[14] Parajuli, Sajjan, A. M. Tiara, Hyeokgyun Moon, Sagar Shrestha, Hao Yang, Jinhwa Park, Younsu Jung, Jinkee Lee, and Gyoujin Cho. "Control of the coffee ring effect during R2R gravure printing for minimizing threshold voltage variation in printed carbon nanotube-based thin film transistors." *Materials Today Advances* 18 (2023): 100385. https://doi.org/10.1016/j.mtadv.2023.100385
[15] Saad, Ashraf Abd El-Rahman Elsayed. "Environmental pollution reduction by using VOC-free water-based gravure inks and drying them with a new drying system based on dielectric heating." PhD diss., Wuppertal, Univ., Diss., 2007.

[16] Hui, Tan Mooi, and Yutaka Asako. "Implementation of Uncertainty Analysis of Temperature Measurement." *Journal of Advanced Research Design* 77, no. 1 (2021): 1-11.
[17] Park, Janghoon, Hyi Jae Kang, Kee-Hyun Shin, and Hyunkyoo Kang. "Fast sintering of silver nanoparticle and flake layers by infrared module assistance in large area roll-to-roll gravure printing system." *Scientific reports* 6, no. 1 (2016): 34470. https://doi.org/10.1038/srep34470
[18] Metaxas, C., and J. L. Driscoll. "A comparison of the dielectric properties of paper and board at microwave and radio frequencies." *Journal of Microwave Power* 9, no. 2 (1974): 79-89. https://doi.org/10.1080/00222739.1974.11688904
[19] Fuller, AJ Baden. *Microwaves: an introduction to microwave theory and techniques*. Pergamon, 1979.
[20] Ylimys, Jussi. "Quality optimisation of the overall paperboard manufacturing process for a rotogravure printing." Master diss., School of Engineering Science, Kemiantekniikka, (2022).
[21] Yoshida, Tsuguaki, Shinichiro Takagi, Yasuhiko Muto, and Teilong Shen. "Register control of rotogravure printing press. Application of nonlinear control theory to sectional drive printing press." *Electronics and Communications in Japan* 94, no. 1 (2011): 17-24. https://doi.org/10.1002/ecj.10282
[22] Lee, Changwoo, Jangwon Lee, Hyunkyoo Kang, and Keehyun Shin. "A study on the tension estimator by using register error in a printing section of roll to roll e-printing systems." *Journal of Mechanical Science and Technology* 23 (2009): 212-220. https://doi.org/10.1007/s12206-008-0927-2
[23] Lee, Changwoo, Hyunkyoo Kang, Hojoon Kim, and Keehyun Shin. "Effect of taper tension profile on the telescoping in a winding process of high speed roll to roll printing systems." *Journal of mechanical science and technology* 23 (2009): 3036-3048. https://doi.org/10.1007/s12206-009-0906-2
[24] Knittel, Dominique, Edouard Laroche, Daniel Gigan, and Hakan Koç. "Tension control for winding systems with two-degrees-of-freedom H/sub/spl infin//controllers." *IEEE Transactions on Industry Applications* 39, no. 1 (2003): 113-120. https://doi.org/10.1109/TIA.2002.807231
[25] Kamble, Vijay, Vasudev Dhondiram Shinde, and Jayant K Kittur. "Overview of load cells." *Journal of Mechanical and Mechanics Engineering* 6, no. 3 (2020): 22-29.
[26] Anusha M, C Vidya Raj, Vinod Kumar H P. "Integration of all types of photoelectric sensors with IoT and development of android based application". *International Research Journal of Engineering and Technology (IRJET).* 8, no. 8 (2021): 1603-1608. https://doi.org/10.26562/irjcs.2021.v0808.004
[27] HYPLAS®. “Rotogravure printing machines (for printing flexible packaging material): ‘HP-RG series – ‘High speed’ type, ‘HP-RG’ series – Standard type.” HYPLAS Machinery Co., LTD.
[28] Mitsubishi Electric (Servo Amplifier & Motors). “Advance servo technology with optical network: MELSERVO J3.”*Japan (MDOC)*, 2011.
[29] OMRON Corporation Industrial Automation Company. “G% series AC servomotor/servo drives with built-in EtherCAT communications: R88M-K/R88D-KNO-ECT.” *Datasheet,* 2023.
[30] Webert, Heiko, Tamara Döß, Lukas Kaupp, and Stephan Simons. "Fault handling in industry 4.0: definition, process and applications." *Sensors* 22, no. 6 (2022): 2205. https://doi.org/10.3390/s22062205
[31] Okwudibe, Chinenye D., and B. O. Akinloye. "Design and simulation of temperature data logger." *American Journal of Engineering Research (AJER)* 6, no. 12 (2017): 14-19.
[32] Pandiyan, Vigneashwara, Wahyu Caesarendra, Tegoeh Tjahjowidodo, and Hock Hao Tan. "In-process tool condition monitoring in compliant abrasive belt grinding process using support vector machine and genetic algorithm." *Journal of manufacturing processes* 31 (2018): 199-213. https://doi.org/10.1016/j.jmapro.2017.11.014
[33] Caesarendra, Wahyu, Triwiyanto Triwiyanto, Vigneashwara Pandiyan, Adam Glowacz, Silvester Dian Handy Permana, and Tegoeh Tjahjowidodo. "A CNN prediction method for belt grinding tool wear in a polishing process utilizing 3-axes force and vibration data." *Electronics* 10, no. 12 (2021): 1429. https://doi.org/10.3390/electronics10121429
[34] Ciaburro, Giuseppe. "Machine fault detection methods based on machine learning algorithms: A review." *Mathematical Biosciences and Engineering* 19, no. 11 (2022): 11453-11490. https://doi.org/10.3934/mbe.2022534
[35] Niekurzak, Mariusz, Wojciech Lewicki, Hasan Huseyin Coban, and Milena Bera. "A model to reduce machine changeover time and improve production efficiency in an automotive manufacturing organisation." *Sustainability* 15, no. 13 (2023): 10558. https://doi.org/10.3390/su151310558