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Design and analysis of pneumatic based automatic unwind splicing on a rotogravure machine

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Abstract

The aim of this design is to obtain a design for the tension control system and the automatic system, which are the two mechanisms in the unwind, accompanied by an estimate of the design costs. The design process was carried out using the French method. This method is often used for new products or still has few competitors, with the advantage of being able to facilitate the selection of product concept variants efficiently when designing products that have many limitations in terms of variants. Based on the validation results, the second concept design used is a tension measurement mechanism using a load cell and speed regulation using a magnetic powder brake. The results of numerical calculations show that the maximum rotation torque value of the printed material is 13.6 Nm, the maximum speed is 628.24 rpm, and the maximum stress value measured is 206.122 N. Based on the validation results, the second concept design is a movement mechanism that uses four pneumatic cylinders to move the frame and cutter. The results of numerical calculations show that the time required to cut the material is 0.24 seconds, and the time required to return to its original position is 2.25 seconds. The amount of air required for one cutting cycle is 37.83 ×10-6 m3/s. The estimated cost of designing the overall unwind unit based on the components used is IDR. 74,873,625.

1. INTRODUCTION

Over time, development encourages humans to continue to innovate. A revolution is a fairly fundamental change in a field quickly and concerns the basic principles of people's lives (Muchran & Harryanto, 2019). The industrial sector is a sector that is constantly experiencing change. Starting with Industrial

Revolution 1.0, which was marked by the discovery of the steam engine for the production of goods; Industrial Revolution 2.0, which was marked by the transition from the use of steam power to electric power; and Industrial Revolution 3.0, which was marked by the entry of information and electronic technology into the industrial world (Kartika, 2021).

The global technological transformation will cause updates to the existing industrial order (Estriyanto et al., 2021). Currently, the packaging printing industry is experiencing development and improvement, so it cannot be denied that there will be intense competition between companies (Bagasharo & Prastiwinarti, 2022).

One type of packaging that is commonly used is flexible packaging. Flexible packaging is packaging made from flexible materials so that it can be filled with goods in various shapes (Waladow, 2019).

Since its discovery in the 15th century, there has been very rapid development in the rotogravure printing industry (Wasono, 2008). Unwind is the part that channels the printing material to the machine continuously and evenly during the printing process (Wasono, 2008). This part has two main mechanisms, namely, the unwinding process and the splicing process.

Unwinding is the process of unrolling the printed material and distributing it to the rotogravure machine printing unit. This process has a tension control system that adjusts passive tension to maintain consistent tension when the system suddenly starts or stops (Xie et al., 2017).

Splicing is the process of cutting printing material when the roll is almost used up so that it can be replaced with a new roll using pneumatics as the drive system. Pneumatics is a drive system that utilizes compressed air to provide a pushing or pulling force (Indriyanto et al., 2018).

2. RESEARCH METHODS

This research uses the French design method. This method is method is often used for new products or those that still have few competitors (Hutabarat, 2020). This method is considered able to facilitate the selection of product concept variants efficiently of product design, which has many limitations in terms of variants (Purwo and Widigdo, 2019).

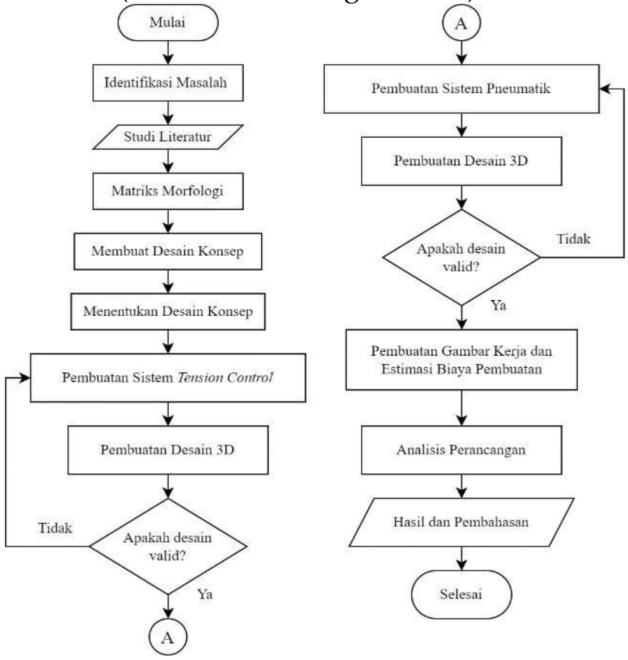

Figure 1. Research flow diagram

3. RESULTS AND DISCUSSION

3.1. Identify The Needs

The unwinding process mechanism starts by inputting the printing speed and printing material tension values on the control panel. The input signal will give the order to rotate the electric motor so that the printing material will rotate and supply the printing material to the next process. When the printing material begins to be supplied, the tension of the printing material will be measured by a tension sensor, which will then be transmitted to the control system. The control system will process the measurement results and compare them with the input values. The control system will order the actuator to maintain the tension of the printed material according to the input value.

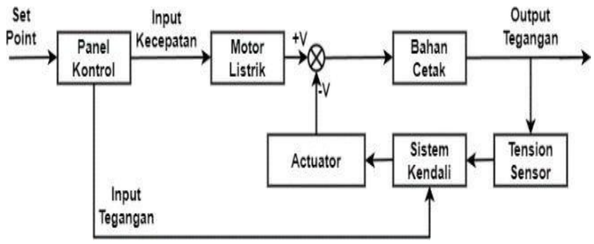

Figure 2. Unwinding mechanism block diagram

The splicing process mechanism starts from pressing a button to provide a signal to the control system. The control system will command the actuator to operate and cut the printed material.

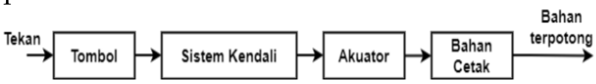

Figure 3. Splicing mechanism block diagram

3.2. Morphological Matrix

The morphological matrix is useful in developing new ideas by classifying designs based on several element ideas that are used to be combined later so that possible variations in design concepts emerge from the combination of various elements (Nabil & Jamaluddin, 2023).

Table 1. Unwinding Morphology Matrix

Sub-Function Elements	Mechanic
A. Control Panel	1. HMI
B. Tension Sensor	1. Dancer Roll
	2. Load Cell
C. Actuator	1. Diaphragm Piston
	2. Magnetic Powder Brake
D. Energy Transfer	1. Gear
	2. Pulley
	3. Kopling
E. Electric Motor	1. None
	2. Motor servo
F. Control System Unwinding	1. PLC

Table 1 shows that it can be arranged into design concept variants. The following are concept variants based on the morphological matrix:

a) Variant 1 = A1-B1-C1-D1-E2-F1
b) Variant 2 = A1-B2-C2-D1-E1-F1

Table 2. Splicing Morphology Matrix

Sub-Function Elements	Mechanic
A. Button	1. Push Button
	2. Detent Switch
B. Control System	1. Full-Pneumatic
	2. Electropneumatic
C. First Actuator	1. Double Acting Cylinder
	2. Single Acting Cylinder
D. Second Actuator	1. None
	2. Double Acting Cylinder
	3. Single Acting Cylinder
E. Cutter	1. Serrated cutter
	2. Roll cutter

From table 2 it can be arranged into design concept variants. The following are concept variants based on the morphological matrix:

a) Variant 1 = A1-B2-C1-D1-E2
b) Variant 2 = A1-B2-C1-D2-E1

3.3. Creation and Selection of Concept Design

Based on the concept variant which is composed of component selection in the morphological matrix, the concept design of the variant is visualized in 3D form.

3.3.1. Unwinding Concept DesignVariant

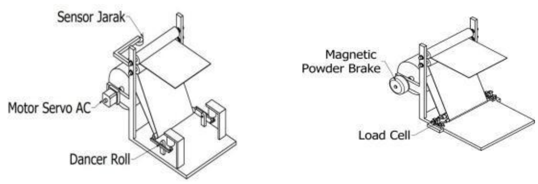

Figure 4. Variant I (a) and Variant (b) Unwinding

3.3.2. Splicing Concept Design Variant

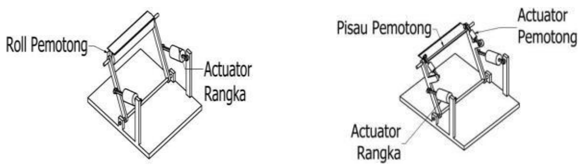

Figure 5. Variant I (a) and Variant (b) Splicing

The selection of the concept design was carried out by asking for an assessment from 2 lecturers who were experts in the field of design. The assessment procedure is carried out by providing a questionnaire containing concept designs and then selecting the one that is the best design. Based on the selection of results, the concept design for unwinding products is the second concept design, and the concept design for splicing products is the second concept.

3.4. Component Analysis

3.4.1. Chasis

The chassis was analyzed using the Finite Element Analysis (FEA) method using Autodesk Inventor Professional 2020 software

Table 3. Results of FEA

Item	Max Von Misses Stess (MPa)	Max Displacement (mm)	Min Safety Factor
Unwind Chasis	8.36	0.076	24.76
Infeed Chasis	2.36	0.016	87.71
Lower Chasis	19.39	0.138	10.67
Upper Chasis	7.34	0.045	28,2
Stand Chasis	2.91	0.001	71.13
Gears	31.1	0.126	6.65

The analysis results show that the gearbox component's smallest safety factor value is 6.65. However, the safety factor value of 6.65 is still considered safe, considering that the safety factor value for designs with static loads is in the range of 1.2-2 (Pratama and Agusman, 2023:19) and 3-4 for the use of materials that have not been tested on environmental conditions, load and average pressure (Juvinall, 2012:276). This shows that the component design being tested has met the safety factors.

3.4.2. Magnetic Power Brake

The selection of magnetic powder brake specifications is based on the value of torque and speed rotation, and heat dissipation. Several known variables are presented in Table 4.

Table 4. Variables for magnetic powder brake

Variable	Value
Speed (v)	150 m/min
Stress (N)	68 N
Diameter roll maximum (Dmax)	400 mm
Diameter roll minimum (Dmin)	76,2 mm

From these variables, it can be used to calculate torque, rotational speed, and heat dissipation using equations (1), (2), and (3).

Torsion Calculation

$$T = \frac{-}{2} \times F \quad (1)$$

$$Tmax = \frac{0.4\ m}{2} \times 68\ N = 13.6\ Nm$$

$$Tmin = \frac{0.0762\ m}{2} \times 51.8N = 2.584\ Nm$$

Rotation Speed Calculation

$$N = \frac{v}{\pi\ x\ D} \quad (2)$$

$$Nmin = \frac{150}{\pi\ x\ 0.4} = 119.36\ rpm$$

$$Nmax = \frac{150}{\pi\ x\ 0.0762} = 628.24\ rpm$$

Heat Dissipation Calculation

$$P = 0.0167\ x\ F\ x\ v \quad (3)$$

$$P = 0.0167\ x\ 51.8\ x\ 150 = 170.43\ W$$

3.4.3. Load Cell

In selecting a load cell, it is necessary to know the maximum force value ($Fdim$) that works on load cells. Several known variables are presented in Table 5.

Table 5. Known variables for Load Cell

Variable	Value
Web Tension ($Fweb$)	68 N
Roll Weight ($Froll$)	28,98 N
Overload Factor (K)	1,5
Height of center point (H)	53,6 mm
Center point distance (L2)	47 mm
Angle corner (Z)	0°
Printed Material Corner (X)	107,2°

From these variables, it can be used to calculate the maximum force value using equations (4) and (5).

$$Fload = 2 \times F_{web} \times sin\left(\frac{x}{2}\right) \quad (4)$$

$$Fload = 2 \times 68 \times sin\left(\frac{107.2}{2}\right) = 109.46\ N$$

$$Fdim = \frac{2K \times F_{load} \times H + F_{roll} \times L_2}{2L} \quad (5)$$

$$Fdim = \frac{2\ x 1.5\ x\ 109.46\ x\ 53.6 + 28.98\ x\ 47}{2\ x\ 47} = 206.122\ N$$

The size of the pneumatic cylinder is selected considering the load that must be pushed or pulled. In this design the cylinder used has a bore size of Ø10 mm to move the cutter and Ø16 mm to move the frame. Each cylinder has an auto-switch sensor as an input signal to the control system.

3.4.4. Pneumatic Cylinder

The size of the pneumatic cylinder is selected by consider the load that must be pushed or withdrawn. In this design the cylinder used has a bore size of Ø10 mm for moves the cutter and Ø16 mm for move the frame. Each cylinder has an auto-switch sensor as a provider input signal to the control system.

Based on the results of the Festo Fluidsim simulation with a compressor pressure of 7 bar, the throttle valve is open 70%, and the one-way flow control valve is open 40%; the results obtained are that the cylinder forward stroke speed is 0.28 m/s and the reverse stroke speed is 0.04 m/s. The specifications of the cutter drive cylinder can be seen in Table 6.

Table 6. Specification of Cutter Drive Cylinder

Variable	Value
Cutting Mass (m)	0,65 Kg
Gravity (g)	9,8 m/s^2
Bore	10 mm
Rod	4 mm
Stroke(s)	0,03m
Piston area (A1)	78,5 x 10^{-6} m
Ring area (A2)	66 x 10^{-6} m
Load ratio (η)	0,3
Operating Pressure (P)	7 bar
Force forward (F1)	16,485 N
Force steps back (F2)	13,860 N
Forward speed (v1)	0,28 m/s

Based on the simulation results of the Festo Fluidsim software with a compressor pressure of 7 bar, the throttle valve is 60% open, and the one-way flow control valve is 30% open; the results obtained are that the cylinder forward stroke speed is 0.21 m/s and the reverse stroke speed is 0.02m/s. The specifications of the frame drive cylinder can be seen in Table 7.

Tabel 7. Frame Cylinder Specifications

Variable	Value
Cutting Mass (m)	3 Kg
Gravity (g)	9,8 m/s^2
Bore	16 mm
Rod	5 mm
Stroke (s)	0,03m
Piston area (A1)	201 x 10-6 m
Ring area (A2)	181 x 10-6 m
Load ratio (η)	0,3
Operating Pressure (P)	7 bar
Force step forward (F1)	42,21 N
Force steps back (F2)	38,01 N
Forward speed (v1)	0,21 m/s
Back speed (v2)	0,02 m/s
Time forward (t1)	0,14 detik
Time Backwards (t2)	1,5 detik
Advanced air requirements(Q1)	10,05 ×10-6 m^3/s
Reserve air requirements(Q2)	3,62 ×10-6 m^3/s

The pneumatic system is controlled by electropneumatic system. Scheme designed using Fluidsim Festo software. The form of the system circuit wiring diagram. The pneumatics used are presented in figure 7.

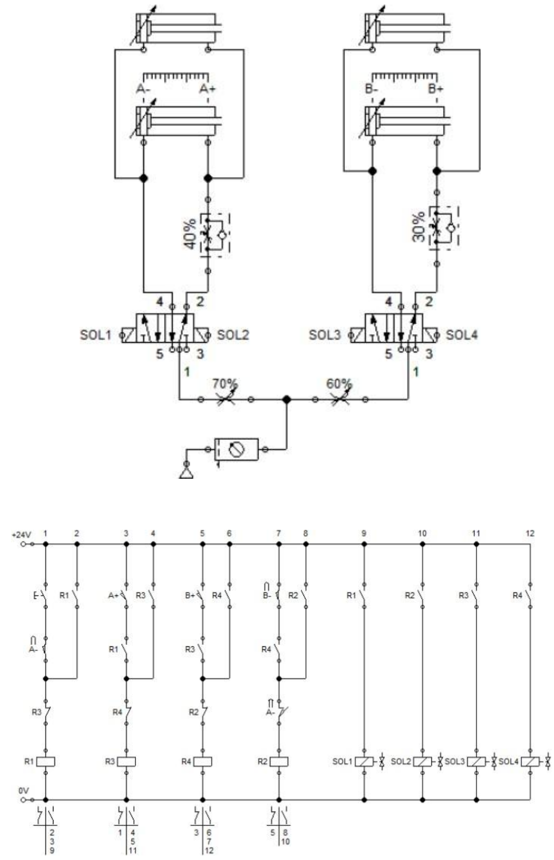

Figure 6. Wiring Diagram Electropneumatic

3.5. Estimated Design Costs

The results of the estimated design costs show that the component costs for the unwinding product are Rp. 56,502,098, component costs for splicing products are Rp. 12,129,150, and the machine production cost is IDR 6,242,377. So the total cost required to make an unwind unit is IDR. 74,873,625.

4. CONCLUSION

The conclusions obtained are the maximum rotational torque value of the printed material is 13.6 Nm, the maximum speed is 628.24 rpm, and the maximum stress value measured is 206.122 N. Based on the validation results, the concept design The second concept design used is a movement mechanism using 4 pneumatic cylinders to move the frame and cutter. The results of numerical calculations show that the time required to cut the material is 0.24 seconds and the time required to return to its original position is 2.25 seconds. The amount of air required for one cutting cycle is 37.83 ×10-6 m3/s. The estimated cost of designing the overall unwind unit based on the components used is IDR. 74,873,625.

5. DECLARATION/STATEMENT

5.1. Acknowledgment

Thank you to all parties who have helped with this research.

5.2. Author Contribution (required)

Arif Rahmadhi contributed to writing the paper, collecting the data, performing the analysis, and contributing data or analysis tools. Wirawan Sumbodo, Danang Dwi Saputro, and Ari Dwi Nur Indriawan Musyono contributed supervision paper.

5.3. Conflict of Interest

The authors declare no conflicts of interest.

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