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Optimized Design for the Flap Folding System of a Carton Sealer Machine by Automation

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Abstract. This study presents the design and implementation of an automated flap folding system for a carton sealer machine in a beverage manufacturing industry in Indonesia. The system addresses the inefficiencies of the manual folding process. The design focuses on affordability by employing a fully electric system, eliminating the need for additional compressors and air tubes. Fabrication utilizes materials available in the company's workshop, with a total cost of IDR 7,243,452. Testing reveals that the system's maximum capacity is 36 cartons per minute, surpassing the current capacity of the carton sealer machine. This results in a production increase from 19 cartons per minute to 30 cartons per minute (58%). Additionally, this research offers substantial cost savings compared to purchasing new carton sealers with automatic flap folders, with potential savings of IDR 45,000,000 per machine if the system is mass-produced.

Introduction

As manufacturing evolves, automation has become essential for increasing productivity, reducing costs, and ensuring consistent product quality, even in the food and beverage industry [1]. Packaging, an integral part of this process, plays a crucial role in quality control during transportation and storage [2].

Carton sealer machines are an effective packing solution available in the market today. These machines apply adhesive tape to packaging boxes using a device called a tape head. In this system, the adhesive side of the tape is applied to the top of the carton, and as the carton moves through the machine, the tape is automatically cut. However, most box designs have flaps that must be folded before sealing. To address this, an automatic flap folding system was developed. This system allows the flaps to fold automatically before sealing, reducing labor costs and increasing productivity. The project will be implemented at a beverage manufacturing company in Indonesia. Currently, the company uses conventional carton sealer machines. While these machines are functional, they face challenges such as delays, labor intensity, and operator fatigue, which lead to reduced production capacity and a higher risk of product defects [3].

The primary issue with the existing carton sealer is the accumulation of cartons on the conveyor between the packing and sealing stations, even though the average packing speed is 15 cartons per minute and the sealing speed is 19 cartons per minute. This problem arises from human inefficiency in the sealing process. Before sealing, the operator must manually fold the flaps on the front, back, and sides of the carton to allow the machine to apply the tape. However, every few minutes, the operator must stop the conveyor to resupply the packing station with new cartons and straws from the storage area. This increases operator fatigue, reduces efficiency, and raises the risk of product and carton defects. Moreover, human inefficiency prevents the carton sealer from operating at its maximum capacity of 30 cartons per minute, thereby reducing overall production capacity. This research focuses on designing an optimized automatic flap folding system for the existing carton sealer and the carton sizes produced by the company. The system aims to eliminate inefficiencies, reduce manufacturing costs, and adapt to the available materials, tools, and production line conditions, enabling full fabrication in the company workshop.

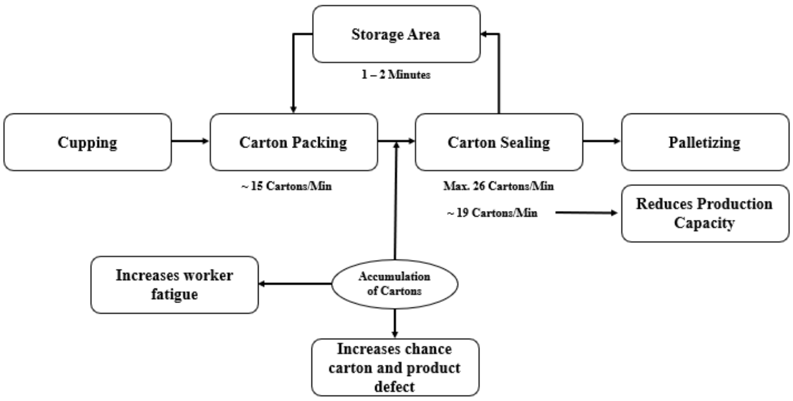

Fig. 1. The production process and problem identification.

Fig. 2. MH-FJ-1D carton sealer.

The company currently uses the MH-FJ-1D Carton Sealer. With a combination of top and bottom conveyors, the MH-FJ-1D ensures smooth and consistent carton movement. Additionally, with adjustable height and width settings, the MH-FJ-1D can seal a wide range of carton sizes. It is also compatible with larger diameter tapes, reducing downtime for tape replacement. These customer-friendly features ultimately increase productivity by minimizing employee training time [4]. However, manual flap folding still requires additional labor, leading to increased labor costs.

Table 1. MH-FJ-1D Carton Sealer Specification.

MH-FJ-1D Carton Sealer Specification	
Power Supply	1P, AC 220 V, 50 Hz, 400 W
Sealing Speed	19 m/min
Machine Weight	100 kg
Weight Capacity	40 kg
Tape Size	48 – 72 mm
Machine Size	L970×W890×H(table top add 700) mm
Working Table Height	530 – 750 mm (tunableness)
Carton Size	L150 – ∞ mm; W180 – 500 mm; H120 – 480 mm
Noise	≤ 75 DB
Capacity	30 Cartons per minute

Methodology

This study employs an automatic folding flap system driven by an electronically controlled stepper motor, managed via an Arduino Uno microcontroller. The core components of the control system include the Arduino Uno, a stepper motor driver, sensors for feedback, and supporting electrical elements. Below is a detailed description of each component and its role in the system, along with a schematic overview to facilitate replication.

Stepper Motor and Driver

The folder arm is a critical component in developing the automatic flap folding system. It is responsible for folding the inner back side of the carton flap and is driven by an actuator in a rotary motion. The folder arm consists of two parts: the puncher and the arm itself. To prevent bending, the arm's surface is positioned perpendicular to the ground, as it is made from a thin stainless steel plate. The stepper motor serves as the actuator for the automatic flap folding system. Choosing the correct stepper motor is crucial to ensure proper machine function. Before selecting the motor, the required torque to rotate the folder arm must be calculated using the rotational form of Newton's second law for rigid bodies [5], with the additional consideration of torque produced by gravity. The Total Torque T_{Req} in the Eq. (1) is required to rotate the folder arm (Nm). I is the Moment of

Inertia of the folder arm ($kg.m^2$). α is the Angular Acceleration (rad/s^2). T_g is the torque needed to overcome gravity (Nm).

$$\mathrm{T}_{Req} = I \times \alpha + \mathrm{T}_g \quad (1)$$

Assuming a uniformly distributed mass, the moment of inertia can be estimated by approximating the folder arm as a solid rectangle. With these assumptions and approximations, the moment of inertia of the folder arm can be calculated using the parallel axis theorem [6], as shown in the Eq. (2). I is the Moment of Inertia of the folder arm ($kg.m^2$). I_{CoM} is the Moment of Inertia from the center of mass of the plate ($kg.m^2$). m is the total mass of the folder arm (kg). d is the distance between the CoM and the rotational axis of the folder arm (m). The result of equation derivative and the values to calculate the moment of inertia of the folder arm, as shown in the Eq. (3).

$$I = I_{CoM} + m.d^2 \quad (2)$$

$$I \approx 0.0042\ kg.m^2 \quad (3)$$

After calculating the moment of inertia, the next step is to calculate the angular acceleration of the folder arm using the Eq. (4), where, α is the Angular Acceleration (rad/s^2). ω_f is the final angular velocity (rad/s). ω_i is the initial angular velocity (rad/s). t is the time required to reach the desired velocity (s). Since the folder arm starts from a resting position, the initial angular velocity is 0. The desired final angular velocity is 120 degrees per second, or approximately 2.1 radians per second, and the time to reach this velocity is 0.1 seconds. By inputting these values into equation (4), the results of α is $21\ rad/s^2$. After determining the moment of inertia and the desired angular acceleration, we can input the values into Eq. (1), the result of $\mathrm{T}_{Req}$is $0.7\ Nm$. With the required torque to move the folder arm calculated, we select a suitable stepper motor by consulting the manufacturer's datasheet. After reviewing the datasheet [7], the Double Stack Nema 23 Stepper Motor is determined to be the most appropriate choice for the project.

$$\alpha = \frac{\omega_f - \omega_i}{t} \quad (4)$$

Power Supply, Wiring and Connections

The main block serves as the foundation where most of the components of the folding system, including the stepper motor and folder arm, will be attached. This component forms the backbone of the folding system's support structure. It is constructed from a stainless steel plate folded into a hollow rectangular beam. One end of the beam is sealed with a plate for bolting to other supporting structures, while the opposite end remains open to allow the folder arm to rotate. Additional openings are made for easier access during assembly and disassembly.

The top guide is used to fold the front inner side of the carton flap as the carton moves through the system. It also keeps the back inner flap of the carton closed after being folded by the folder arm. The top guide consists of two parts: the guide itself and the holder, which connects the guide to the main block. Like other components, the guide is made of stainless steel plate. The side guide folds the outer side flaps of the carton using curved rods to fold the flaps from incoming cartons. Since stainless steel plates cannot be used to form rods, we decided to purchase hollow stainless steel pipes with a 10 mm diameter and 2 mm thickness. The side guide comprises two components: the holder block and the pipe. The holder block allows the pipe to rotate, and M6 bolts are used to fasten the pipe and connect it to the connector support, as shown in Fig. 3 and 4.

Microcontroller and Sensors

The connector support serves as the main support structure for the automatic folding system. It connects all the components of the system and links them to the carton sealer machine. The structure is attached where the emergency button was previously located, as the button has been moved to the control panel. To ensure durability, we use 4.5 mm steel plates instead of the standard 2.5 mm stainless steel plates. After completing the folding flap design, some modifications were made to the carton sealer machine. These include mounting the sensor, disassembling the front roller, extending the machine guide bar, and drilling bolt joints for the folding flaps.

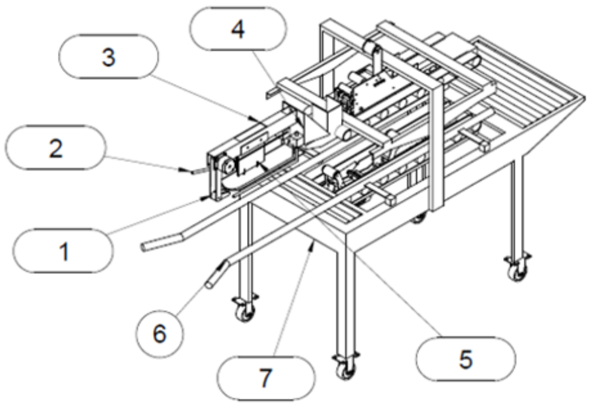

Fig. 3. MH-FJ-1D with automatic folding flaps final design, with detail part (1) Folder arm, (2) Side guide, (3) Main block, (4) Connector support, (5) Top guide, (6) Extended guide bar, and (7) Removed front roller.

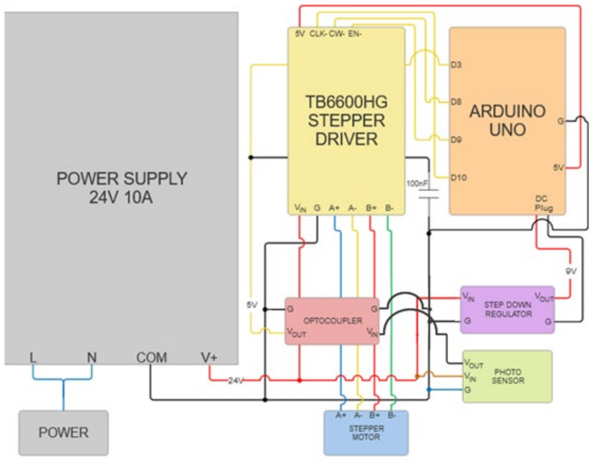

Fig. 4. Automatic folding flaps electrical system.

Table 2. Automatic folding flaps fabrication data.

No	Component Name	Dimension	Material	Tools	Process
1	Connector Support	Plate 170mm × 170mm × 4.5mm (1) Plate 120mm × 150mm × 4.5mm (2)	Steel ASTM A36 Steel ASTM A36	Hand Grinder, Hand Drill, Welding Machine	Cutting, Boring, Welding, Polishing
2	Top Guide Holder	Plate 150mm × 171mm × 2.5mm (1)	Stainless Steel AISI 304	Hand Grinder	Cutting, Bending
3	Arm	Plate 30mm × 215mm × 2.5mm (2)	Stainless Steel AISI 304	Hand Grinder	Cutting
4	Puncher	Plate 60mm × 30mm × 2.5mm (1)	Stainless Steel AISI 304	Hand Grinder, Welding Machine	Cutting, Bending, Welding
5	Main Block	Plate 400mm × 200mm × 2.5mm (1)	Stainless Steel AISI 304	Hand Grinder, Welding Machine	Cutting, Bending, Welding
6	Top Guide	Plate 500mm × 100mm × 2.5mm (1)	Stainless Steel AISI 304	Hand Grinder, Hand Drill, Welding Machine	Cutting, Bending, Welding
7	Holder Block	Block 40mm × 40mm × 40mm (1)	Aluminum	Hand Grinder, Hand Drill	Cutting
8	Pipe Guide	Pipe 600mm × 10mm × 2mm (1)	Stainless Steel AISI 304	Hand Grinder	Cutting

Table 3. Automatic Folding Flaps Fabrication Cost.

Type	Name	Cost (IDR)	Total Cost (IDR)
Material	Steel ASTM A36 and Stainless Steel AISI 304 Plates	808,196	1,359,590
	Stainless Steel AISI 304 Plates	238,894	
	Pipe Holder Aluminum Blocks	312,500	
	Stepper Motor	364,583	
	Stepper Driver	166,667	
Electrical	Arduino Uno, Step Down Regulator, Optocoupler, Cables	313,854	1,345,729
	Photo Sensor	312,500	
	Power Supply Unit	188,125	
Human Resource	Human Resource	4,535,133	4,535,133
Total Cost			7,240,452

Results and Discussion

After the fabrication and assembly process, the machine was tested directly on the production line, operating alongside the manual folding flaps. The first goal was to determine the maximum capacity of the automatic folding flaps to ensure that the system's capacity is equal to or greater than that of the carton sealer machine. The capacity of the automatic folding flaps can be calculated using the Equation (5), where, C is the maximum capacity of the automatic folding flaps ($cartons/minute$). L_{Carton} is the length of the carton (cm). D_{Min} is the minimum distance between cartons (cm). v_{conv} is the conveyor speed ($cm/second$).

$$C = \frac{v_{conv}}{L_{Carton} + D_{Min}} \times 60 \quad (5)$$

It is important to note that the minimum distance depends on the conveyor speed. A higher conveyor speed results in a larger minimum distance. The conveyor speed of our production line is 26 cm/s, and after several trials, we found that 12 cm is the minimum distance the folding system can handle at this speed. The capacity of the automatic folding flaps system at a conveyor speed of 26 cm/s is 36 cartons per minute. We can now compare the capacity of the automatic and manual MH-FJ-1D with other carton sealer machines that have automatic folding flaps available in the market, as shown in the Fig. 5.

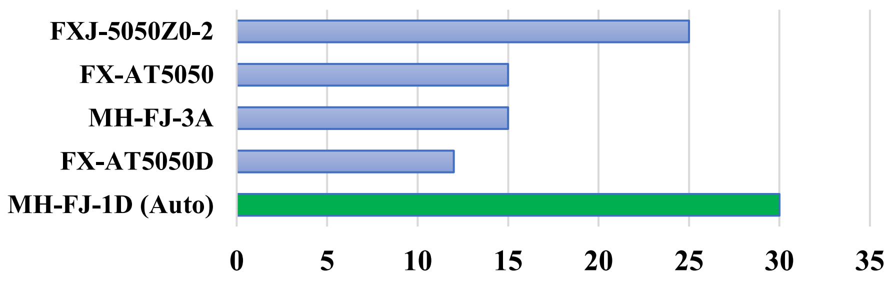

Fig. 5. Capacity of Various Carton Sealer Machines with Automatic Folding Flaps.

As depicted in Fig. 5, most carton sealer machines with automatic folding flaps in the market have a capacity of less than 20 cartons per minute, with the exception of the FXJ-5050Z0-2. This is because the folder arm design is often large and heavy, which results in slower movement speed due to the increased energy required to move the arm. If the heavy arm moves too quickly, it can transfer excessive kinetic energy into the system, making it unstable. However, a larger folder arm is advantageous for larger cartons with longer back inner flaps. Our automatic folding flaps system, on the other hand, is optimized for small to medium-sized cartons. Additionally, the production capacity of the company increased by 58%, from 19 to 30 cartons per minute.

Another reason for designing and fabricating our own automatic folding flaps is to save costs compared to purchasing a new carton sealer machine with automatic folding flaps. The total cost savings are presented in the Table 4.

Table 4. Cost Saving Data.

	FXJ-5050Z0-2 (IDR)	FX-AT5050 (IDR)	MH-FJ-3A (IDR)	FX-AT5050D (IDR)	GPC-50D (IDR)	Out-House Workshop (IDR)
Prize	41,006,000	47,407,656	52,500,000	40,522,676	42,000,000	12,000,000
Project Cost	7,240,452	7,240,452	7,240,452	7,240,452	7,240,452	7,240,452
Cost Saved	33,765,548	40,167,204	45,259,548	33,282,224	34,759,548	4,759,548

As shown in Table 4, we saved up to IDR 45,000,000 by developing this project. It is important to note that this is the cost savings for producing one automatic folding flap system. The company could save significantly more if they choose to mass-produce the automatic folding flaps for all production lines in their factories across Indonesia. Based on Table 4, the project cost to develop the automatic folding flap system is IDR 7,240,452. Compared to procuring comparable automated systems such as FXJ-5050Z0-2 or FX-AT5050, the direct cost savings per system range from approximately IDR 33.7 million to IDR 45.3 million. ROI quantifies the financial return relative to the initial investment, expressed as a percentage:

$$\text{ROI (\%)} = \frac{\text{Cost Saved per System}}{\text{Project Cost}}\times 100 \tag{6}$$

The cost-benefit analysis reveals a highly favorable return on investment, with the lowest savings scenario of IDR 33,765,548 resulting in an ROI of approximately 466.3%, while the highest savings of IDR 45,259,548 corresponds to an ROI of about 624.9%, demonstrating that the project offers substantial financial benefits relative to its initial development costs. The analysis demonstrates that the MH-FJ-3A automatic folding flap system yields an exceptional ROI, with payback periods well under one month per unit. Scaling this solution across multiple production lines could generate millions of IDR in savings, compelling strong justification for mass production. This strategic investment not only cuts costs but also boosts productivity and operational flexibility, providing long-term benefits for the company.

The automatic folding system shows great improvements in capacity and efficiency, but there are some limitations to consider (a) Different carton sizes: The system was tested with a specific size of cartons. Larger, smaller, or irregularly shaped cartons might not fold as accurately or quickly. Future work should focus on making the system adaptable to various sizes. (b) Material types: The system is designed for certain materials, like specific types of cardboard. Thicker or different materials might cause issues with folding or damage the cartons. Testing with a range of materials is needed to improve compatibility. (c) Environmental conditions: Factors like humidity, temperature, and dust can affect the system's parts and performance. High humidity, for example, might cause parts to rust or warp. (d) Scaling and customization: Expanding the system for larger or different production lines could present new challenges, such as fitting into different factory layouts or working with existing machinery. (e) Maintenance and operator skills: The system needs proper upkeep and trained operators for optimal performance. Lack of skills or resources could reduce system reliability over time.

Conclusion

The designed automatic folding system consists of eight components, with a focus on using available materials as much as possible. The electrical system was handled by my supervisor, who served as the electrical engineer for the project. The fabrication process was completed in the company workshop using a hand bore machine, hand grinder, and welding machine. The total cost for the fabrication and assembly of the project was IDR 7,243,452. After several trials on the production line, we calculated that the maximum capacity of the automatic folding flaps is 36 cartons per minute, exceeding the maximum capacity of the carton sealer machine. This allows the machine to perform at its full capacity, increasing the company's production capacity by 58%, from 19 cartons per minute to 30 cartons per minute. The comparison of difference capacity of the automatic and manual MH-FJ-1D with other carton sealer machines that have automatic folding flaps also shows that the automated MH-FJ-1D has the highest capacity. The project saved up to

IDR 45,000,000 per machine if the company decides to mass-produce the automatic folding flaps for their other MH-FJ-1D carton sealer machines. Acknowledging the potential limitations emphasizes the importance of further testing and iterative development to enhance the system's robustness and adaptability. Addressing these factors will ensure that the automatic folding system can be reliably implemented across diverse production scenarios, maximizing its benefits for the company.

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