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Design and Implementation of A Hot Sealing System on A Bag Machine Based on PLC

Tauhid Tauhid, Nana Sutarna, Handri Santoso
Politeknik Negeri Jakarta, Indonesia
Email: tauhid_te22@mhswa.pnj.ac.id, nana.sutarna@elektro.pnj.ac.id, handri.santoso@elektro.pnj.ac.id

ABSTRACT

This research aims to design and implement a hot sealing system using a hot sealing machine. The type of sealing machine used is a fully automatic continuous hot sealing machine, developed from the manual hot sealing type that uses tape-sealing bags (duct tape). The quality standard for the sealing results must refer to ASMEF88. The methodology used in this research involves observing and identifying damages in the sealing bags at PT. X, followed by planning solutions and actions based on field findings. A review of the old sealing bag machine is conducted, and a new model of the sealing bag machine is designed. Next, observations and cost calculations for the system technology to be used are carried out, and the appropriate machine system and control program are planned. Subsequently, system simulations and program designs are performed based on observational data, followed by the assembly and testing of the built system. Trials and performance tests of the machine and the sealing bag process are conducted. The system performance and sealing bag quality results are then evaluated, and improvements are made according to the ASMEF88 standard. Finally, analysis and preparation of the final report are carried out. Data recording and documentation of this process have been conducted throughout the observation, planning, implementation, and final evaluation stages. The design and implementation of the automation machine and monitoring system will involve PLC components and IoT technology, enabling real-time system monitoring during the process. The final result of this research is expected to reduce the occurrence of broken sealing in packaging bags.

KEYWORDS *broken sealing, Hot Sealing, PLC, IoT, monitoring system*

INTRODUCTION

The adhesive strength of packaging is crucial in maintaining the integrity of its contents. If the adhesive strength is poor, several problems can occur, including the easy opening of the packaging, contamination of the contents, and potential spillage. Therefore, the quality of the adhesive strength of packaging requires close attention. This issue is evident in the packaging of plastic pellet seeds sealed with adhesive sealing tape at PT. X, which experienced adhesion damage ranging from 2.15% to 21.62%, affecting 222,800 to 236,000 units of production. This incident was detrimental to the company, as numerous complaints were received from consumers. Such conditions represent a serious problem that must be evaluated and remedied within the existing adhesive system (Alim et al., 2021; Ivey et al., 2021; Lyu et al., 2024; Vrabič-Brodnjak, 2023).

The company's improvement effort involved replacing the sealing tape system with a manual hot sealing system, where the clamping or hot sealing process is operated by personnel working in rotating shifts for 24 hours non-stop (Lazarević et al., 2020; Murmura et al., 2021; Sichinsambwe et al., 2023; Urbaniak et al., 2023). While repairs using this system proved helpful in reducing damage, production output decreased by 4% to 14% compared to the target. Based on this case, an in-depth review of the manual hot sealing machine currently in use is necessary to determine the true root cause of the problem (Ou et al., 2016).

Based on reference sources and literature studies, obtaining good adhesion quality in packaging bags depends on the adhesive process and technique. The material of the packaging bag is also an important factor in selecting the gluing technique (Langley et al., 2021; Teodor et al., 2020). For plastic materials, hot sealing is generally used, although vacuum system gluing techniques also exist. In hot sealing techniques, the adhesive process must consider three parameters: temperature, material, and cooling process. These parameters need to be maintained and controlled throughout the gluing process to achieve high-quality results (Amida et al., 2022; INOUE et al., 2016; Taheri et al., 2023; Yamada et al., 2015). Studies have shown that instability often occurs in maintaining these parameters during hot sealing. Similar observations have been reported by other researchers, noting temperature fluctuations in the packaging during the hot sealing process, even when PLC and other automation systems were used for control. Research by attributes the cause of packaging strength damage to inadequate control of piston pressure and heater temperature. Furthermore, researchers, stressed the importance of monitoring pneumatic movement and the torque of the driving cylinder (piston), as well as sealing time, during the hot sealing process to ensure adhesive quality. Meanwhile, highlighted that sealing control processes must pay close attention to the calculation of heating parameters over time. These studies indicated that adhesion failures in hot sealing may result from errors in the set point reference values.

Drawing from these findings and the aforementioned case studies, this research focuses on developing an improved heating system control through the regulation of the on-off heating ratio over time and implementation of a cooling system, using an automated PLC program, to achieve heating stability in the sealing bag machine. By optimizing these parameters, sealing damage can be reduced by up to 99.9%. The resulting ratio settings will be monitored in real-time to determine the values that deliver optimal sealing results.

Based on the identified problems and literature review, this study proposes a research project on the *design correction of manual hot sealing* and the *system implementation of automated hot sealing*. The automation will compare heat levels, process time, and cooling system performance in relation to sealing quality. The primary objective is to *design and implement an automatic heating control system* in a hot sealing machine by adjusting the on-off heating ratio and cooling system via a PLC program to achieve optimal heating stability and minimize sealing damage by up to 99.9%. The benefits of this research include enhanced product quality and consistency, improved production efficiency, reduced damage and waste, and providing a scientific foundation for the broader adoption of more effective automatic hot sealing machines in the manufacturing industry.

RESEARCH METHOD

The methodology used in this research was to design a hot sealing system with a clamping process operated by a piston and controlled by a PLC. Performance testing of the hot sealing machine was then conducted to evaluate the quality of the packaging adhesion. Several tests were performed to adjust the heat ratio, process time, and cooling system to achieve minimal damage to the adhesive seal. The target was to reduce the packaging adhesion damage rate to 0.5%.

Data collection involved direct observation, performance testing of the hot sealing machine, and continuous monitoring of packaging adhesion results across multiple experiments with varied heat ratio, process time, and cooling settings. The data were obtained from the machine's output, including the percentage of adhesion damage, temperature readings, and runtime records. Data analysis utilized real-time monitoring and statistical evaluation to identify the optimal combination of heat, process time, and cooling ratio that minimized damage. The research was carried out at the hot sealing machine production facility, with all testing and system implementation performed under operational conditions to ensure the practicality and reliability of the results.

RESULT AND DISCUSSION

Adhesion or Adhesion or sealing process in some sealing machines or sealing machines in small and large industries generally use the heat transfer method because of its density and durability. Electronic temperature control is used to produce sealing seams of constant quality. The use of temperature regulators is beneficial, especially when working with thick film materials , as the temperature can be kept constant over a predetermined period of time. The method used by the plastic packaging industry depends on the thermal conductivity of the film material. If the heating of the sealing area is slow, the timer will cause overheating of the film in direct contact with the heating tape. However, if a temperature regulator is used, all materials will be heated to the required temperature level only.

In the observation, this research was carried out on observations or case studies contained in PT. X where the sealing results in each shift have products that fail in sealing or gluing more than 2%.

The data on the results of damaged bags using the Impule sealing cycle type sealing machine for each shift is obtained according to the following table.1

Table 1. Table of broken bag results per shift.

Date	Shift	Bag Out machine (bag)	Broken bag.	Percentage
08-Aug-2024	**Shift** 1	4800	103	2,15%
	Shift 2	4800	285	5,94%
	Shift 3	4800	122	2,54%
09-Aug-2024	**Shift** 1	4800	132	2,75%

Date	Shift	Bag Out machine (bag)	Broken bag.	Percentage
	Shift 2	4800	128	2,67%
	Shift 3	4800	139	2,90%
10-Aug-2024	**Shift** 1	4800	123	2,56%
	Shift 2	4800	185	3,85%
	Shift 3	4800	127	2,65%
11-Aug-2024	**Shift** 1	4800	130	2,71%
	Shift 2	4800	111	2,31%
	Shift 3	4800	135	2,81%
12-Aug-2024	**Shift** 1	4800	133	2,77%
	Shift 2	4800	619	12,90%
	Shift 3	4800	422	8,79%
13-Aug-2024	**Shift** 1	4800	124	2,58%
	Shift 2	4800	141	2,94%
	Shift 3	4800	165	3,44%
14-Aug-2024	**Shift** 1	4800	140	2,92%
	Shift 2	4800	121	2,52%
	Shift 3	4800	119	2,48%
Average Broken per shift		4800	136	2,83%
Average Broken per day		14400	330	2,29%

In the case of production of 4,800 packages, there was a failure of the sealing bag (reject) between 2.15% and 12% for each shift. The solution that has been done so far is to reset the temperature of the sealing heater if the packaging production is above 1000 bags. So far, heating temperature regulation has been carried out by trial and error because there has been no certainty of a reference standard. The impact of the failure percentage on the sealing bag results varies for each production shift.

The sealing results in the above method there are unstable heating problems during the sealing process above 1000 bags according to the results of the method Impulse sealing cycle graphically shown in the Image. 1 below.

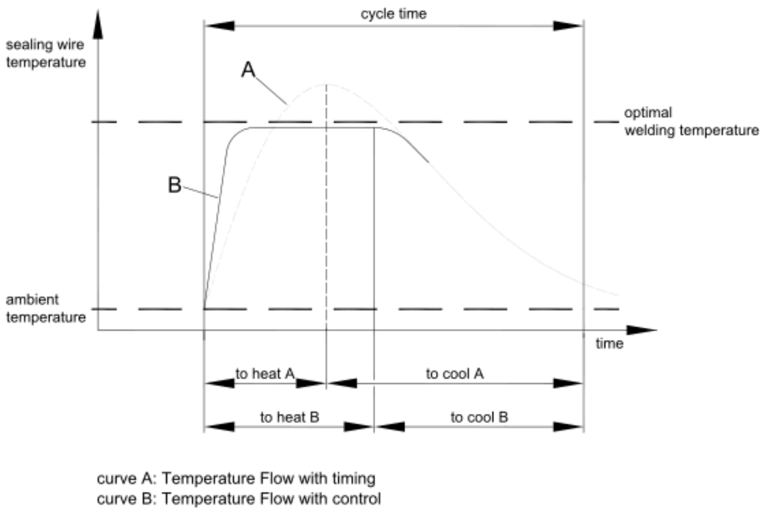

Figure.1 Impule Sealing Cycle Method

The results used in this sealing repair are to compare the heat generated to the time or process of the sealing and the cooling system by following some of the formulas below;
The first is to determine the power in the heater, which can be calculated with the equation. (1)

$$P = \frac{V2}{R} \quad (1)$$

Where:
P = Power (watts)
V= Tegangan (volt)
R= Resistance/Resistance (ohms)

Next, calculate the Energy (w) on the *plastic* material to be used using the Equation. (2)

$$W = mPlastic \times Cplastic \times Plastic \quad (2)$$

Where:
W= Energy (Joules)
mPlastic = plastic weight time (kg)
Cplastic = Hot type plastic (J/kg.$^{oC)}$
Tplastik = Temperature plastic ($^{oC)}$

From the above equation, the heat transfer (h) in the material is then calculated using the equation. (3)

$$h = \frac{W}{\pi.D^1.L.\Delta T.\Delta t} \quad (3)$$

Where:
h = heat transfer coefficient
W = Energy
D1= Diameter (m)
ΔT= Selisih T1-T2 ($^{oC)}$
Δt= Time difference(s)

Next, it looks for the calculation of the rate of heat change (Q), using equations. (4)

$$Q = \frac{\Delta T}{\Sigma R\text{Th}} = \frac{T1-T2}{R\ Heater+R\ Barrel+R\ plastik} \quad (4)$$

Where:

RHeater = $\frac{ln(^{rH}/_{rO})}{2.\pi.KH.L}$

RHeater = $\frac{ln(^{rH}/_{rO})}{2.\pi.KB.L}$

RHeater = $\frac{1}{h.A1} = \frac{1}{h.\pi.L.D1}$

The sealing time data is obtained from the results of calculations with the pneumatic system used as well as the amount of air flow or cooling at the time of sealing using the following equations;
First the calculation on the speed of the Piston, using equations. (5)

$$V = \frac{s}{t} \quad (5)$$

Where:
s = Sroke lengt (cm)
t = time(s)

while in Flow cooling air (Q) using an equation. (6)

$$Q = \frac{\pi}{4} D^2 x\ v \quad (6)$$

Where:
Q = Flow udara (l/s)
D2 = Pipe diameter (cm)
V = Velocity Piston (l/s)

Table 2. Table of broken bag results per shift after using the cooling ratio.

Date	Shift	Bag Out machine (bag)	Broken bag.	Percentage
20-Oct-2024	**Shift** 1	4800	56	1,17%
	Shift 2	4800	58	1,21%
	Shift 3	4800	61	1,27%
21-Oct-2024	**Shift** 1	4800	56	1,17%
	Shift 2	4800	58	1,21%
	Shift 3	4800	60	1,25%
28-Oct-2024	**Shift** 1	4800	66	1,38%
	Shift 2	4800	59	1,23%
	Shift 3	4800	71	1,48%
30-Oct-2024	**Shift** 1	4800	62	1,29%
	Shift 2	4800	82	1,71%
	Shift 3	4800	61	1,27%
5-Nov-2024	**Shift** 1	4800	62	1,29%
	Shift 2	4800	93	1,94%

Date	Shift	Bag Out machine (bag)	Broken bag.	Percentage
	Shift 3	4800	89	1,85%
Average Broken per shift		4800	136	66,3
Average Broken per day		14400	330	198,8

Data from corrections to repairs using *hot sealing* machines showed a 1.17% reduction rate of damage from 4,800 bags. Although there has been a decrease in the number of rejected packaging, the result is still considered high. The adhesion failure occurred in the left, right and middle edge areas.

The results of the hot sealing machine repair with heat ratio, runtime, and cooling system settings showed a significant decrease in the rate of packaging damage, from an average of 2.83% to 1.17% per shift. This decline is supported by the theory of heat transfer and industrial process control, which states that temperature stability and precise heating timing can improve product quality (Incropera & DeWitt, 2011). The results of this study are in line with the findings of Putra et al. (2020), who showed that optimization of heat and cooling ratios in plastic sealing machines can significantly reduce the rate of adhesion failure through more accurate thermal control. Despite the decrease in damage, the damage site was still concentrated in the left, right, and center edge areas, indicating the need for additional evaluation of the heat distribution on the film surface as well as the calibration of the piston and cooling airflow to ensure heating homogeneity. This analysis confirms that the combination of thermodynamic calculations, heating-cooling ratio control, and real-time monitoring is an effective strategy in improving the performance of hot sealing machines, while strengthening the understanding that heat transfer theory and process control are the scientific foundation for optimizing industrial product quality.

CONCLUSION

The automated design and programming of the hot sealing control system, which regulated the on-off heating and cooling cycles through a PLC based on the heat-to-time ratio, successfully improved sealing quality stability from 2.15%–12% damage down to 1.17%, with a production output of 4,800 bags per shift. For future research, it is recommended to further develop the Impulse sealing cycle method by optimizing the cooling ratio through a PID-controlled temperature system and refining the gap configuration in the cooling process to achieve greater efficiency and precision in sealing performance.

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