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Control System Development of Cap-Seal Assembling Machine

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Abstract

The cap-sealing assembling machine is vital in various packaging industrial sectors, particularly the oil sector. The conventional control system of such machines suffers from many demerits, e.g. low productivity, high production cost, high rejection rate, and requires frequent maintenance. Therefore, the current research aims to develop a new control system (N.C.S) based on a programmable logic controller and human-machine interface system (PLSC&HMI). Hence, a fully automated cap-sealing assembling machine can be achieved. The machine is used to produce cap seals for engine oil containers. The performance of the new control system machine is evaluated and compared with the conventional control system (C.C.S) to examine the system feasibility and reliability. The aspects that are subjected to evaluation are the daily working hours (hrs.), glue consumption (Kg), and rejection rate (%). The independent t-test is conducted to deliver a fair comparison and approve the effectiveness of the proposed control system. The obtained findings give the significant development of the proposed control system based on the dependent t-test result. The working hours are reduced to 31.15 hours, and maintenance durations are lowered to the minimum. Also, the N.C.CS reduces the rejection by increasing the accuracy of the finished cap sealed from 88.3 to 99.42 % and consumed glues from 11.5 kg to 7.11 kg.

Keywords: *PLC, HMI, Lubricants, control, packaging*

1. Introduction

Capping and sealing machines enable firms to protect the packaged products during handling, storing, and shipment until the machines are reached to the hands of the customers. Automated systems are becoming more significant and interesting for the industrial sector and economics. Automated systems produce potential merits, e.g. reducing product cost, waste, labor, improving production quality, reliability, and repeatability. Hence, the automation of different machines can achieve the mentioned goals. Sealing machines are widely utilized in manufacturing and have typical applications, e.g. sealing and packaging. In the 80's, hand sealing was performed using gloves to press the heated foils on the containers. This is not a reliable operation and has many demerits. Thus, such machine automation has started occupying the sealing industry for many products. Recently, more companies have begun changing their manual assembling to automated mode using industrial robots and automation [1]. The automated capping and sealing equipments provide unlimited merits for the industrial packaging sector. The automated equipment strongly enhance productivity by reducing workers' number, directing the workers to only manually-concentrated tasks, and protecting the workers from toxic and unsafe operating conditions. Further, automated equipment lower production costs, sustain qualified packaged products, maintain hygienic circumstances, and avoid direct hand contact to eliminate probable product contamination.

The control strategy of the different packaging machines have to fulfill some needs, including speed tuning, coordinating between the detected and executed parts, controlling the driving units, enabling a smooth, active sequence of tasks, and ensuring a secure and safe operating mode to protect the operators [2]. Numerous studies have been conducted in developing industrial automation control systems to resolve the troubleshooting associated with manual and semi-automatic machines. For instance, Adizue U. L et al designed and fabricated a small-scale automated can foil sealing machine. The machine was tested later and obtained an efficiency of 78% [3]. Mingyu Gao et al. developed an automatic assembling system for the sealing of rings by using machine vision [4]. Experimental findings showed that the developed system could grab and place the sealing rings on the sealing port speedily and successfully. D.Kanimozhi et al [5] designed and fabricated a mini and simple packaging machine using PLC software to control and automate the packaging process. The productivity was increased, and production time decreased by using this system. SU.Hema et al. [6] Developed and implemented a successful automatic filling and sealing machine. Several features were added for different stages of the work, such as defined volume specification. PLC was adopted to control various operations and the monitoring process was done by using SCADA System.

Md Abu Sayeed and Md. Rafiquzzaman [7] developed an automated system for PE bags. The developed system supplied plastic bag using vacuum grippers and accomplished the sealing process automatically. The polyethylene bag was hanged with dead weight to evaluate the sealing strength. Anca and Carman [8] proposed a PLC control system for injection molding to increase the yield rate of flowerpot products. In addition to the IMO iSmart ED-RD-20 PLC, the system involves a 24 V DC power supply, DC motors, temperature sensors, input and output LEDs, buttons, and switches. The PLC was programmed by the Ladder language and validated with simulator software. The proposed system was successfully implemented. Abueejela et al. [9] presented a PLC control system for a small-scale packaging machine. Small cubic woods with 2.8 cm3 each were packaged into an 18 cm3 paper box. The Mitsubishi FX2n 32MT PLC was fed with data through inductive and photoelectric sensors. The PLC was programmed by ladder language. DC motors drive the output actuators to move cubic wood on the conveyor belt, which receives a signal from the control system. The presented system showed good performance by packaging twenty-one boxes every minute. A PLC control system for a traditional vertical injection machine was proposed by Cui et al. [10]. The achieved results revealed that the performance of the automated machine was characterized by fast, efficient, reliable, and stable performance compared with the old control system that entirely relied on the relay control strategy.

Manhas et al. [11] automated the motion of the conveyor belt by using a PLC control system to improve the productivity of the bottle-filling production line. Also, the filling level was automatically controlled within a particular time in seconds to ensure that all bottles were filled with the required amount. A Mitsubishi PLC was programmed by ladder language and simulated by GX Work 3 software. The achieved findings agreed with the specified parameters in the LD program. Luo [8] designed a PLC control system for packaging machine. The performance of the designed PLC system, according to the author, has improved the production capacity, operating stability, and provided intuitive and convenient working platform.

The cited work in majority adopted PLC system to control the traditional machine and to improve their performance in terms of some indexes. The current study motivation is to develop and implement a PLC-HMI control system for cap seal assembling machine to solve the issues correlated to real industrial problems. The challenge for implementing the developed control system comes from the fact that this machine works within a set of other machines in a production line. The machine incorporates sub-operation that must be precisely controlled and coordinated to confirm a smooth production cycle with high productivity, good quality, and fewer maintenance periods.

2. Development of New Control System (N.C.S) for Cap Seal Machine

The current cap seal assembling machine works within a set of other machines that form an integrated production line of engine oil assembled in Al-Dorah oil refinery. This production line involves injection molding machines for caps and plastic containers, cap seal assembling machines, and packaging machines. Any stoppage in any of those machines stops production and cause extra losses consequently affect the monthly production plan and cause a failure to satisfy market demand. These losses are considered warranted due to conventional control systems incorporated in these machines. The machines mostly include independent electronic circuits that rely mainly on relays and timers. The Cap seal assembling machine is selected among other machines to develop the control system. Developing the control systems is crucial due to the many sequential tasks that the machine delivers.

The process flow of this machine begins with feeding the hopper with unglued caps. The caps are directed by the sorter orienteer to the conveyer belt to be identified by the cap detector to prepare them for gluing. The hot melted glue is deposited on the interior surface of the caps by the seal gun. The seal gun consists of a nozzle that injects a certain amount of glue controlled by a solenoid valve. An aluminum foil ribbon winded on a roller is cut into circular strips to be placed on the glued caps and pressed by the piston. The caps are passed onto all these sub-operations by a star wheel driven by a motor and camshaft. Figure 1 depicts the four sub-operations while the entire machine, including the hopper, feed sorter, hot melted glue, old HMI, and finished sealed caps, are illustrated in Figure 2.

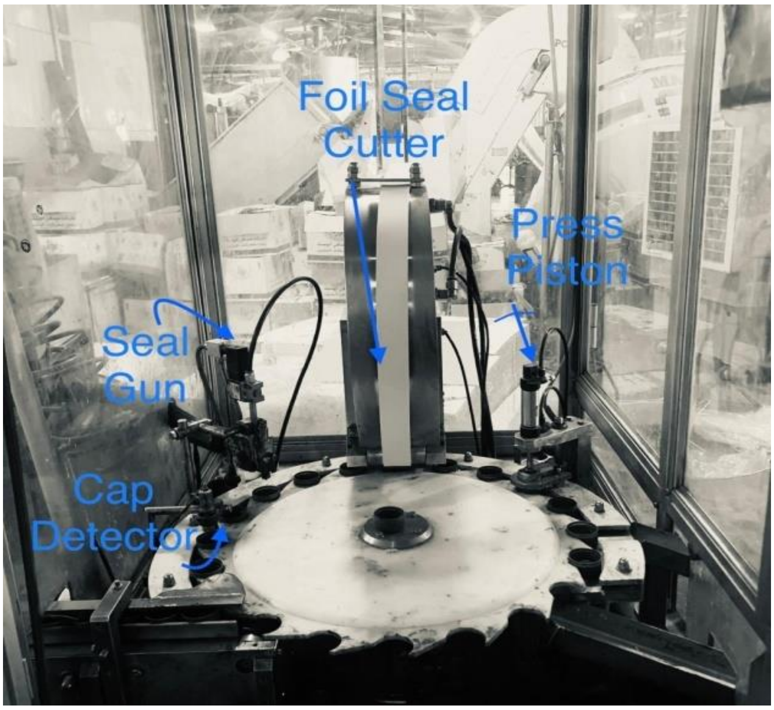

Fig. 1. Four sub-operations of cap seal machine.

Fig. 2. Entire cap sealing machine.

This machine has many problems:

1. Low production rate
2. Delay in response time.
3. High rejection rate
4. High consumption of glue and seals
5. Needs frequent maintenance.
6. Lack of harmony and coordination between sub-operations due to independent conventional electronic circuits for each one.
7. Lack of safety emergency stop.

The frequent maintenance of this machine is due to several issues of the conventional control system that depend entirely on the relays and timers. And among those issues, there are the frequent delays caused by extra or less amount of eccentric injected glue and under or over-phase placing of the star wheel. The right machine phase means the four caps must be placed under the right locations: cap detector, glue gun, seal cutter, and pressing piston, as depicted in Figure 1. Other caps are located between the four active caps. The electrical and mechanical issues occur due to the delay in the relay signal to the cutter and press piston and mechanical loose in the movement of the camshaft, respectively. Consequently, they expose the star wheel to be in the wrong phase and subject it to frequent damage if the cutter and piston move down on the star wheel teeth instead of foil seal. These issues cause many stoppages for machine maintenance that may be done weekly or every few days. Furthermore, adding a new function for protection or accuracy to the conventional control system increases the wiring system's complexity and obstacles, considering that these functions should be performed in milliseconds. Figure 3 shows the flow chart of the conventional machine.

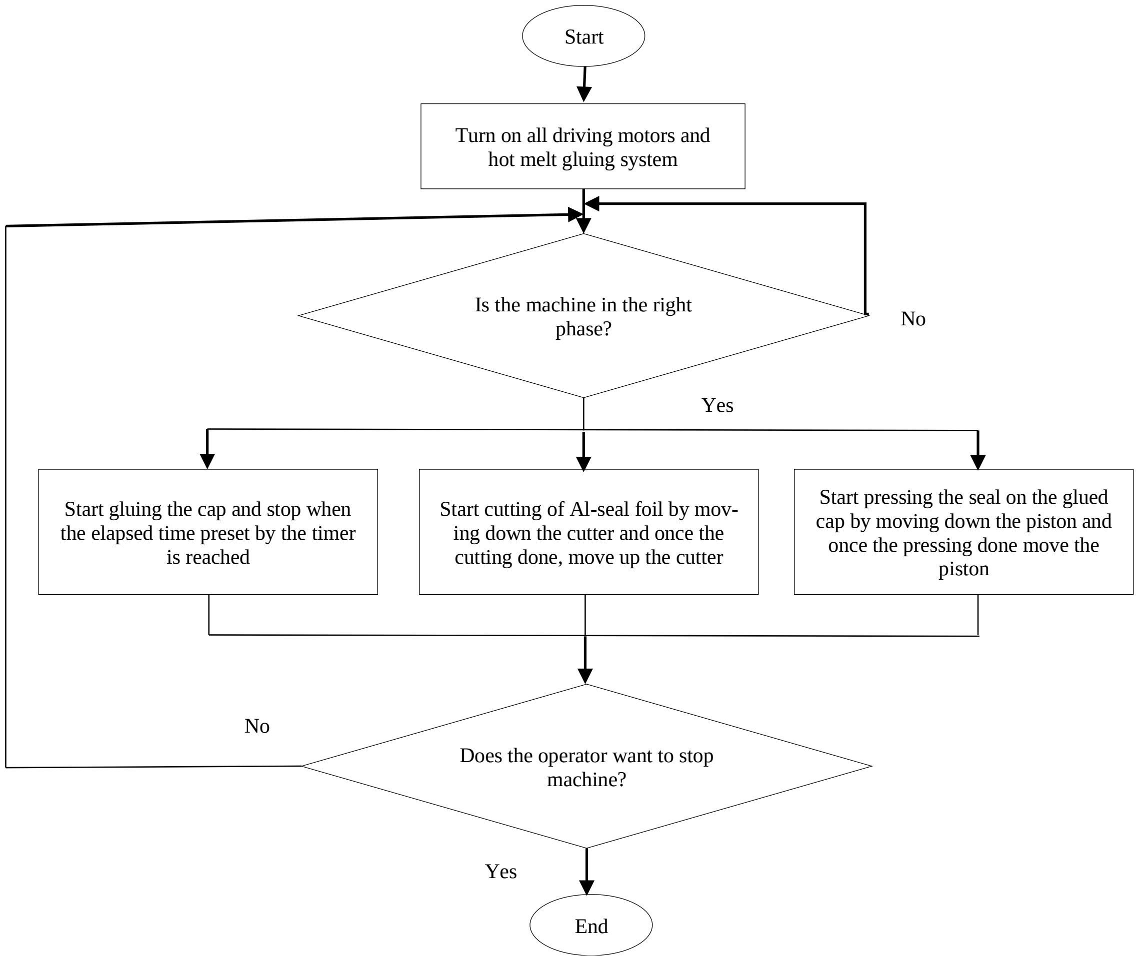

Fig. 3. Flow chart of the conventional control system of cap seal machine.

A Programmable logic control-human machine interface (PLC-HMI) system was developed and implemented to increase productivity, minimize production time, improve product quality, provide safety, lower maintenance, and reduce waste/ scrap materials.

A PLC is generally classified as a microprocessor-based application. The program of machine control is written in ladder. The ladder program consists of three stages; the PLC control system does a particular task in each stage. Omeron PLC is selected in this study to perform the following stages as described below:

1. Ready for start stage: this is the first stage, in which PLC checks the machine operating conditions including all the statuses of machine alignment, drive-motor protection, safety door, cap in loader, instrument air, cap counter, and Hot-Melt system. If all these statuses are OK, the machine is considered ready to start; otherwise, the alarm appears on the HMI.
2. Startup stage: in this stage the operator presses the start push button once he receives the signal of ready to start. The PLC sends signal to the driver motor to start the machine. There are four DC driving motor: the first one drives the conveyor belt between the hopper and sorter to provide continuous feeding of unglued caps; the second motor drives the sorter, which maintains all the caps are placed on the on their outer surfaces; the third motor drives the second conveyer belt between sorter and star wheel; finally, the star wheel rotates by the motor and camshaft to distribute cups on the right phase in which one cap is located to correct the
3. Running stage of cap seal assembling machine: in this stage, the PLC receives the signal that ensures the caps exist on the conveyor belt. At the same time, the PLC checks the positive and negative edge signals of the machine phase sensors. Once the PLC receives the positive signal, the PLC delivers an order to the cutter and piston to move upward and start gluing the cap with the hot melted glue by the glue gun, cut the Al-foil seal by moving down the cutter, and press down the seal on the glued gun by the piston. Otherwise, a negative edge

signal is delivered to the PLC in case both the cutter and pressing piston are in the down positions. The hot melt system stops the glue injection by signal from the PLC when the injection time is elapsed. Also, when the cutter and pressing piston actions are done, the PLC delivers a signal to the cutter and piston to move upward and stop cutting and pressing. The operator uses the HMI to set both numbers of caps that must be sealed and elapsed time for injecting glue. When the PLC receives a signal that a new cap seal is produced, the counter starts to count and compare the number of the made cap seal with the pre-set number selected on the HMI by the operator, as illustrated in Figure 4. If the number of glued and sealed caps is reached, the machine automatically stops; otherwise, the production cycle continues until it reaches the preset number of final products.

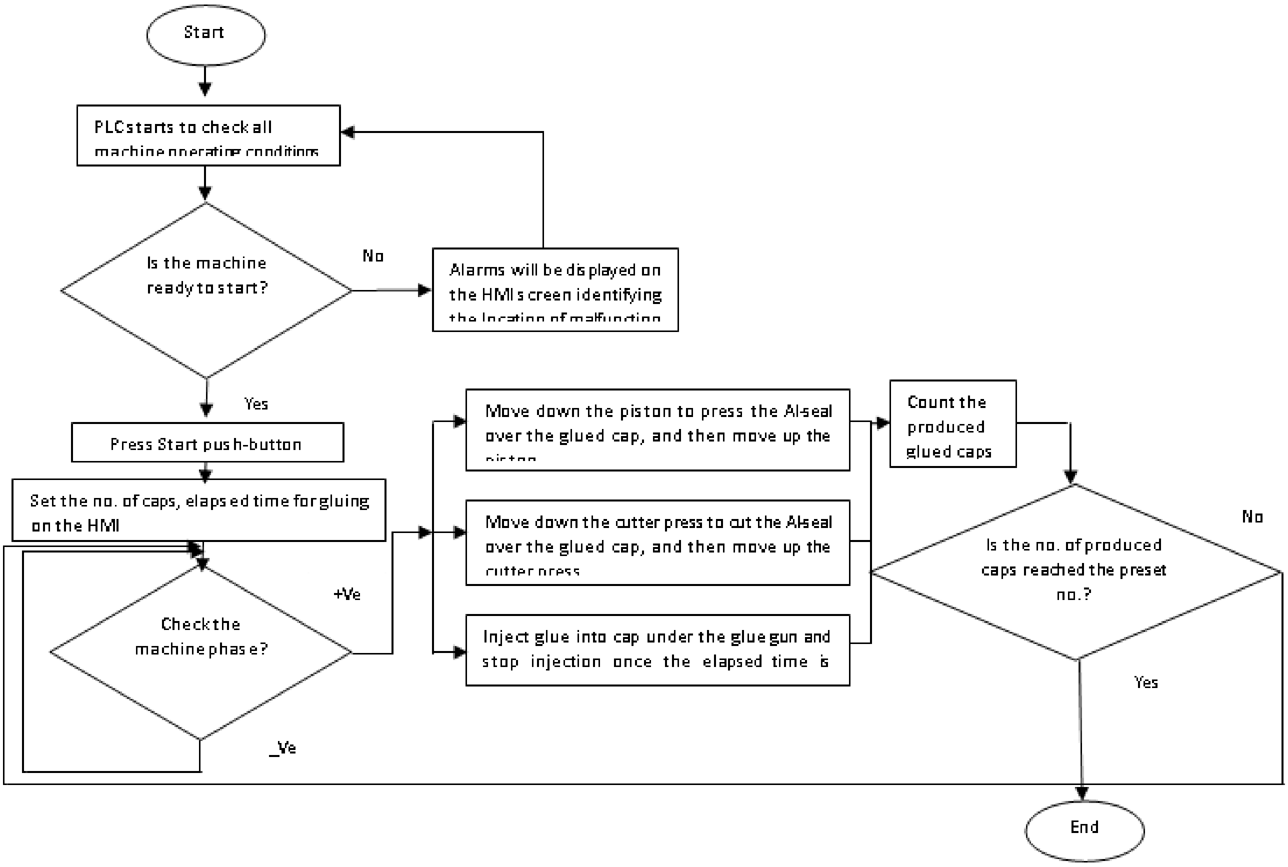

Fig. 4. Flow chart of the new control system (N.C.S) for the cap seal machine.

3. Results and Discussion

The preceding section has described the developed PLC-HMI system integrated with the cap seal machine. In this section, the performance of the new control system was evaluated based on some key aspects compared with conventional control machine. The working hours (Including maintenance time), rejection rate (%), and amount of the consumed glue in kg (include the wasted glues).

The production plan for each machine is to produce 40,000 cap seals in 20 working days. The daily working hours, rejection rate, and consumed glue were recorded as shown in Table 1.

Three parameters were considered in this study, as illustrated in the above table. The bottom of Table 1 shows the sum, average, maximum, minimum, and standard deviation of each parameter for both machines. It is clear from the table that the reductions in working hours and consumed glue were 61.22 hours and 3.39 kg, respectively. The noticeable decrease in the working hours was due to the elimination of maintenance time included in the working hours. The maintenance time for the C.C.S machine was necessary to clean the glue system's components, which is the reason for the increasing working hours.

On the other hand, the maintenance time was reduced to minimum levels (annually) for the N.C.S machine due to the insertion of the developed PLC-

HMI system. That means the machine can be able to continue in production without stopping during the working hours. The rejection rate is an important aspect that plays a crucial role as a key performance index of the evaluation. The reduction in the average rejection rate was 11.125%. In other words, the rejection rate was reduced down to 0.575%. The high amount of the consumed glue is consistent with the high rejection rate of the C.C.S machine.

The standard deviation values of the three parameters for the N.C.S machine were much less than the corresponding ones of the C.C.S machine. This reveals that the fluctuation of the collected data around the mean values is less after modification. In contrast, there was high deviation of the observations around the mean for the C.C.S machine. Also, the maximum and minimum values of the three parameters ensure this behavior. This reflects the stability of the N.C.S machine and its effectiveness compared with the C.C.S one.

Figure 5 shows the control system of the cap seal machine with the PLC-HMI system. Figure 6 shows the cap seal product produced by C.C.S and N.C.S machines.

There is evident a difference in the quality of the cap seal before and after modification of the machine in terms of the texture of the cap / seal and the amount of injected glue and its distribution.

To examine the reliability of the developed PLC-HIM system, it is better to conduct the dependent t-test using SPSS. The experimental data in table 1 is subjected to this test to check the validity of the modification made by the developed system on the machine's efficiency. The null hypothesis supposes that the average output of each parameter is the same before and after development. SPSS was fed with collected data to run the dependent t-test, and the achieved results were tabulated as shown in Tables 1, 2, and 3, respectively.

Table 2 shows the Paired Samples Statistics and provides the descriptive statistics (i.e., means, number of data sets, standard deviations, and standard errors of means) for both control systems. Table 3 is Paired sample correlations and shows the degree of the correlation between the parameters and the level of significance of the two-tailed test to evaluate the hypothesis of zero correlation.

Table 3 is the Paired Samples Test and shows the results of the t-test analysis. The statistical values given under the label Paired Differences are determined by subtracting C.C.S parameter value from the N.C.S one. The three measures (mean, standard deviation, and standard error of mean) of these differences are provided here with a confidence level of 95% of the mean of differences. The last three columns are the t-test results. The results of this test give the t-statistic values of 11.133, 6.362, and 29.711, respectively. The degrees of freedom are 19 degrees. The p-value of the two-tailed for the three pairs is 0.000, which is much less than the traditional 5% or 1% significance level. Hence, in this case, the null hypothesis can be rejected at a 5% (or 1%) level of significance. That means that the performance of the N.C.S machine with embedded PLC-HMI system has indeed improved and enhanced with a high degree of significance compared with C.C.S machine. Therefore, the developed system has proposed solutions to the existing problems and improved & enhanced the performance of the cap-sealed machine by reducing the rates of all three aspects that were considered in the current study.

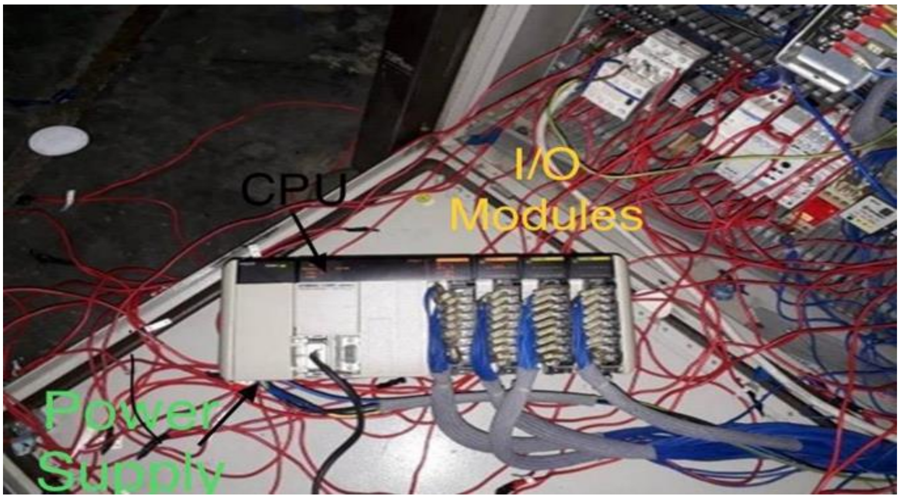

Fig. 5. New control system (N.C.S) of Cap seal assembling machine

Table 1,
Experimental data of conventional and new control systems (C.C.S & N.C.S) for the cap seal assembling machine

No.	Convention Control System (C.C.S)			New control system (N.C.S)		
	Working hours	Consumed glue (Kg)	Rejection rate (%)	Working hours	Consumed glue (Kg)	Rejection rate (%)
1	4	0.6	10	1.5	0.35	0.6
2	3.67	0.4	10	1.5	0.35	0.5
3	4.5	0.65	12	1.4	0.34	0.5
4	5	0.72	13	1.5	0.35	0.5
5	6	0.75	14	1.5	0.35	0.6
6	4.1	0.55	11	1.7	0.38	1
7	3.7	0.4	10	1.5	0.36	0.5
8	3.8	0.46	10	1.4	0.35	0.3
9	4	0.59	12	1.6	0.36	0.6
10	4.5	0.63	12	1.5	0.35	0.5
11	7	0.77	15	1.6	0.35	0.7
12	3.8	0.41	10	1.9	0.39	1
13	3.9	0.42	11	1.5	0.35	0.4
14	4	0.62	10	1.5	0.34	0.4
15	6	0.73	13	1.6	0.35	0.5
16	5	0.71	13	1.5	0.35	0.5
17	8	0.85	15	1.6	0.36	0.7
18	3.7	0.4	10	1.5	0.35	0.5
19	4.2	0.44	12	1.65	0.36	0.6
20	3.5	0.4	11	1.7	0.37	0.6
SUM	92.37	11.5	234	31.15	7.11	11.5
Average	4.6185	0.575	11.7	1.5575	0.3555	0.575
MAX	8	0.85	15	1.9	0.39	1
MIN	3.5	0.4	10	1.4	0.34	0.3
STDEV.	1.225348	0.149543	1.688974	0.116161	0.012344	0.174341

Table 2,
Paired Samples Statistics

Pairs		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Working Hours-C.C.S	4.6185	20	1.225348	.273996
	Working Hours-N.C.S	1.5575	20	.116161	.025974
Pair 2	Consumed Glue- C.C.S	.5750	20	.149543	.033439
	Consumed Glue- N.C.S	.3555	20	.012344	.002760
Pair 3	Rejection Rate- C.C.S	11.7000	20	1.688974	.377666
	Rejection Rate- N.C.S	.5750	20	.174341	.038984

Table 3,
Paired Samples Correlations

Pairs		N	Correlation	Sig.
Pair 1	Working Hours- C.C.S & Working Hours- N.C.S	20	.011	.965
Pair 2	Consumed Glue- C.C.S & Consumed Glue- N.C.S	20	-.349	.131
Pair 3	Rejection Rate- C.C.S & Rejection Rate- N.C.S	20	.134	.573

Table 4,
Paired Samples Test

Pairs		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Working Hours- C.C.S & Working Hours- N.C.S	3.061000	1.229612	.274950	2.485524	3.636476	11.133	19	.000
Pair 2	Consumed Glue- C.C.S & Consumed Glue- N.C.S	.219500	.154289	.034500	.147291	.291709	6.362	19	.000
Pair 3	Rejection Rate- C.C.S & Rejection Rate- N.C.S	11.125000	1.674538	.374438	10.341292	11.908708	29.711	19	.000

(a) (b) (c)

Fig. 6. Glued and glued-sealed caps: (a) glued cap by C.C.S machine (b) glued caps by N.C.S machine (c) cap sealed by the developed machine

4. Conclusions

The current study has proposed a new control system based on PLC-HMI integrated with the cap seal machine. The performance of the developed system has been tested and evaluated by the dependent t-test to claim and ensure the effectiveness and feasibility of its development. It has approved its efficacy and reliability in solving the problems that were associated with the C.C.S machine and improved its performance and functionality through:

1. Reduction of the working hours down to 31.15 hrs.
2. Minimization of the cleanup time to a minimum level.
3. Increasing the accuracy from 88.3% to 99,423% by reducing the rejection rate.
4. The performance of the glue feeding system is highly improved by lowering the glue consumption from 11.5 to 7.11 kg per 40 000 cap seals.

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تطوير نظام تحكم لماكنة تجميع وختم الاغطية

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الخلاصة

تعتبر آلة تجميع وختم الغطاء من المكائن المهمة في مختلف قطاعات صناعة التعبئة والتغليف، وخاصة قطاع النفط. النوع التقليدي ذو نظام التحكم القديم لهذه الآلات يعاني من العديد من العيوب مثل انخفاض الإنتاجية، ارتفاع تكلفة الإنتاج، ارتفاع معدل الرفض، ويتطلب صيانة متكررة. لذلك، يهدف البحث الحالي إلى تطوير نظام تحكم جديد يعتمد على وحدة تحكم منطقية قابلة للبرمجة ونظام واجهة الإنسان والآلة (PLC&HMI) للحصول على ماكنة تجميع وختم الغطاء مؤتمتة بالكامل ليتم استخدامها في علب زيت المحرك. تم تقييم أداء نظام السيطرة الجديد ومقارنته بالنظام القديم لفحص جدواه وموثوقيته. الجوانب التي خضعت للتقييم هي ساعات العمل اليومية، استهلاك الغراء (بالكغم)، ونسبة الرفض (٪). تم إجراء اختبار t الغير مستقل للحصول على مقارنة عادلة بالإضافة إلى التأكد من فعالية نظام السيطرة المقترح. أشارت النتائج التي تم الحصول عليها إلى فعالية نظام السيطرة المقترح بناءً على نتيجة اختبار t. حيث تم تخفيض ساعات العمل إلى 31.15ساعة، كما تم تخفيض فترات الصيانة إلى الحد الأدنى. كما تم تقليل معدل الرفض من خلال رفع دقة انتاج الغطاء النهائي المحكم الغلق من 88.3إلى 99.42%، كما تم تقليل كمية الغراء المستهلك من 11.5كجم إلى 7.11كجم.