Design and Development of Semi- Automatic Filling Machine

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Abstract

The manual filling method was observed by authors at a soy sauce factory in Samutsakhon, South-west of Bangkok. This study provides an efficient and economical method in the packaging process line. A prototype of a semi-automate 25 kg drum filling machine was designed considering cost reduction and built to test and analyze. Computer programs of structure analysis were implemented to design and aluminum profiles were used to construct the main frame, PLC as the main controller and solenoid valves as the flow systems controller. The result showed that the design was able to reduce the unnecessary cost in the process line by minimizing the process errors and skilled labor. The implementation of this machine design can provide economic benefits at industrial scale by reducing process and labor costs.

Keywords: *Filling machine, valves, PLC, Load cell.*

1. INTRODUCTION

For over twenty years of observation in a small soy sauce factory, a number of solutions to problems regarding quality process need to be invented, engineered, and evaluated very carefully to deliver one of the best products to the market. Although many problems can be solved by labor forces but moving forward to an era of automated system seems to be a better idea. After surveying the market, several types of liquid filling machine were observed, but most of them were expensive, and some were not giving the right solutions to the problems. Thus, authors attempted to build a machine that could deliver the most suitable and desirable solutions to the task in the production line of this factory. The efforts led to the development of semi- automated 25kg drum filling machine.

In the current production line, four skilled labors are needed to operate the manual filling process. One team leader uses a breaker switch to control the flow using pump and operate the nozzle. Two other men take over the sanitization of the environment and finish by closing the lid. Then the fourth person will remove the finished drum from the scale while the second man replaces it with the new one. This process is not only time consuming but also less efficient and

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can be inaccurate. Moreover, at least one backup team is needed in the case that the skillful labors refuse to work, which results in an unnecessary cost to be paid.

This easy to use semi-automated filling machine is a prototype machine for SMEs, especially for food industries. The main task of this machine is to precisely fill 25kg plastic drum with liquid. With the load cell, the exact amount of filling can be calculated. Aluminum profile bars were used as its main frame to reduce weight and to control the size of the machine in order to fit the limited space of SMEs. The filling nozzle and other safety inputs were controlled by the "Programmable Logic Controller" or the PLC. According to the prediction and planning of this new production line, it is possible to reduce half of the workforce compared to manual method and moreover the user friendly design of machine can be handled by layman. Maintenance and cleaning of the machine is easy and in accordance with good manufacturing practice (GMP).

2. State of the arts

In the past few years, automation has been preferred at industrial scale. This project is the initial step for many small and household companies to automate their production line. The problem is clearly coming from labor section and it happens to all industries with labor force. This solution will help in lowering the cost for labors while increasing production rate. By reducing filling time and necessary labor force, automation leads to lower risk from human errors. Besides, it is possible for all Small and medium-sized enterprises to consider more automation in their system with a minimum cost and increase in profit. There is a potential for more automation into the system which could lead to 24 hours operation time.

3. Literature review

3.1 General types of filling machines in food industry

Food products of viscous and particulate contents raise the use of filling machines in the industry. This process needs to be highly accurate in order to avoid wastage of materials. All fillers should accurately (±1% of the target weight) fill the container without spillage and contaminating the sealing area. Except for low production rate or particular products (e.g. bean sprout), fillers operate automatically to achieve the required filling speed [1].

Filling machines are set to fill up the cartons, plastic bags or bottles with the exact amount of product as designated. Being a usual part of an assembly line system, filling machine is a vital component of a bottling process. There are several types of filling machine used in various packaging industries. The types which are commonly utilized in the production of goods are liquid filling machine, paste filling machine, powder filling machine and granular filling machine. Liquid filling machine is applied in the production of the liquid-based products such as carbonated drink, perfume, alcoholic beverages, shampoo, oil etc. [2].

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Filling machines for putting liquids into containers can be divided into four basic types; vacuum filling, measure-dosing, gravity filling and pressure filling. Most of the machines are specifically designed to use only one of these four principles. There can be multipurpose machines which uses combination of two methods. Gravity and pressure filling are really suited to the moderately fast filling of low viscosity liquids such as water or fruit juice. They are capable of handling bottles at the rate of around 35/min. For really fast filling vacuum filling is the best method [3].

The methods of filling are divided into two primary categories; the sealed-container system, in which the filling device seals positively against the container; and the unsealed container system, in which the container is left open to the atmosphere during the fill process. The latter one has been used in this particular setup. The relative motion between the container and the liquid dispensing device can significantly affect filling performance. The various relative motions possible are none, raise container, lower valve and vice versa. With the help of a linear guidance system the container can be raised or lowered according to the requirement [4].

3.2 Common process of packaging in food industries

A choice of packaging machinery requires consideration of technical capabilities, labor requirements, worker safety, maintainability, serviceability, reliability, ability to integrate into the packaging line, capital cost, floor space, flexibility (change-over, materials, etc.), energy usage, quality of outgoing packages, qualifications (for food, pharmaceuticals, etc.), throughput, efficiency, productivity, and ergonomics, at a minimum.

The several types of fillers used by the packaging industry are:

A. Auger/agitator filling machines: designed to fill dry mixes, such as flour and sugar. The fillers have a hopper shaped like a cone that holds the mix and puts it in a pouch using an auger screw that is controlled by the agitator.
B. Flow filling machines: designed for liquids, oils, and thin food products. These fillers are designed when they fill a bottle or tube that enters the machine, the ejects the open bottle back onto another conveyor for sealing.
C. Tablet fillers: These are designed for products that are counted by pieces instead of weight. These are designed for small bottles (similar to some of the flow fillers), but the hopper of the filler is setup to permit scan counting of tablets or candy pieces.
D. Positive displacement pump fillers: positive displacement, pump filling machines easily handle a wide range of container sizes, fill volumes and product types. With simple tool-less cleaning and PLC control system, product changeover is fast and easy making these our most versatile fillers.

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3.3 Safety of machine in the factory

During the operation of the production line with human interaction to the machine, safety for operators should be the main priority. However, there can still be certain things not going right such as human errors, and machine errors. Therefore, safety regulations to prevent any accident from happening and protocols to control the situations when it happens are needed. Training and practicing the operators is necessary. "The objective of safety systems is to keep potential hazards for both people and the environment as low as possible by using suitable technical equipment, without restricting industrial production [5]."

3.4 Current production line observation

Current manual filling process line at the observed factory, there are four operators at the filling station with the first operator (filling person) stand on one side of the scale with one of his hand controlling the switch for pump and another controlling the nozzle. Second operator (sanitizing person) stands leftward on the other side of the scale equipped with an alcohol spray ready for sanitization. Third operator stands rightward on the same side as the sanitizing person, equipped with a cap enforcer. Fourth operator (lifting person) stands outside of the area and only comes in when the product is finished [6].

Following production line steps are implemented at the study site:

1. Calibrate the scale
2. Sanitization, hands cleaning
3. Place a new empty drum on the scale
4. First operator (filling person) starts to fill the drum
5. Once the drum is filled, first operator (filling person) lifts off the filling nozzle and place
6. It in the new drum that is simultaneously placed on the side.
7. Second operator (also known as sanitizing person) cleans the mouth and collar area of the
8. Drum with alcohol spray and seals the inner cap.
9. Third operator seals the outer cap.
10. Fourth operator lifts out the finished drum.
11. Second operator replaces the empty spot with a new drum.

Then the cycle is repeated.

3.5 Sanitization

A method for in-place cleaning of valve mechanisms and related equipment used on liquid filling machines in the canning industries: i.e. canning, dairy, beverage, juices, bases, concentrates of all types and flavors etc. whether the filling be in metal, glass, plastic, paper or

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any other type of container. Cleaning is effected by filling the machine with a cleaning liquid, placing containers essentially of the same size as are filled by the machine in filling position, filling the containers with cleaning liquid by opening the valves and, while the valves are open, supplying gas under pressure into the cleaning liquid in the containers thereby causing a turbulent scrubbing action which removes soil. Alcohol is regarded as a cleaning liquid, by spraying it over the container can be significantly sanitized [7].

3.6 Food machinery

The Design of food machinery is a rather complex subject that not only needs all the knowledge necessary for common machinery design but also calls upon food engineering and technology, food science, food rheology, food hygiene, and machinery molding arts [8].

The general requirements should be designed to present a clean external appearance. Food quality paints, especially light colored are commonly used as the machine body finish.

3.7 Summary

In general, human based manufacturing process requires lots of efforts on certain tasks, especially on repeating processes. Errors and other accidental factors that can slow down the production line should be minimized. Therefore, machineries implementation could help increase productivity and simplifies tasks for the workers. For the food industries, machines need to be designed for the safety of the operators as well as the hygiene of food. Sanitization and the environment of the operation is very important and should be set according to standards for food manufacturer. There are many types of filling machines that have been designed and use in food factories, such as Piston Filling Machine for thick particulate food products and Net Weight Filling Machine for bulk products. At the observed plant, the manual filling station is used which is operated by 4 skillful labors, this is time consuming process and its low accuracy is undesirable. Thus, all of these factors are involved in the calculation to design the machine that gives the right solution to the factory.

4. IMPLEMENTATION

4.1 Proposed methodology

The solution we studied provided with the scope of the target tasks for the situation observed at the factory. We approached these problems by designing the framework and system for the machine to answer most of the questions on the topic. The machine must be able to reduce the operation cost of the process line, accurate and consistent enough for the production run, concerned about food safety and ease of maintenance or repair. In order to completely illustrate the machine concept, we built model design. The main frame is made of aluminum profiles, the

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mechanisms are the solenoid valves and linear actuators. We use Siemens PLC as the main controller.

4.2 Design concept

Main goal is to reduce the labor and skill use in the filling process. It must be almost automated and require minimal amount of human input during the operation. Therefore, SFS design concept is "A semi-automated filling machine with minimum human input"

4.3. Components

Mechanical components' roles are to support the structure and facilitate the filling process. The main frame look like an L-Shape lying down when view from the side. The main frame is constructed from extruded aluminum profiles. Fastened together using the screw and nuts. The Load Cell structure is casted aluminum. In order to provide guide to the drum, two sections of aluminum profiles are used for this purpose as a drum guide which also the mounting point for the limit switch.

The nozzle deliveries system is comprised of a nozzle frame and a pneumatics cylinder of 20mm bore diameter. The nozzle frame is attached to two linear guide which is fixed to the main frame to ensure the nozzle glides smoothly all the way down.

The manual filling system currently being used at the observed factory works by the manual control of the on/off state of the pump. The problem with this system is that the pump has to be subjected to the repetition of the change of operation states. The controlling switches are pressed repeatedly for over a thousand times per batch. Therefore, the mechanical wear-out of the equipment are quite high, considering that we use high quality components that are able to endure those stresses. The system also has two other problems, namely; the water hammer effects and speed reduction. The water hammer effects is the result of the initial pressure of the pump. This leads to the foaming effect in the product. The effective speed is reduced due to the pressure drop between the change of pump operation states and the workers' skill of controlling the input amount of products.

The main electrical component is Siemens PLC, S7-1200, 1212C 3XB-40. This PLC is responsible for all inputs and outputs of the system. All the data from sensor is processed by the PLC and in return, actuate the relays output accordingly.

Sensors are physical limit switches, load cell, and buttons. The limit switches are utilized to obtain to location of the drum, nozzle frame position. The load cells are used to weight the final products. Lastly, buttons are used to receive input formation operator.

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Relays and Breaker are used as safety control, in case of electrical surge, short circuit or over load. The circuit design comprise of two systems, the 24V are for PLC and Relays actuator, while 220V system are for sensors, pump and pneumatic system.

Source codes are written in a ladder logic diagram to provide the clearest understanding in the logic. Since this project is to minimize the cost, code optimization is the key.

We designed a two valves system (Figure 1) controlled via PLC output that allowed the pump to operate in only its on state throughout the whole process. The first valve, also known as the 'return valve', will return the product back to the reservoir as a loop. The second valve, which is the 'filling valve', will take the product from the loop and fill it into the drum. While filling, PLC signal will command the return valve to close, providing maximum load of product to the filling drum. After finish filling, the return valve reopens and closes the filling valve, hence repeating the loop. The possibilities of arranging the sequencing of these valve state orders are large. For example; at the 90% of volume filled, we can open the return valve prior to the closing signal of the filling valve to reduce the pressure and the mass flow rate, thus, avoiding some spillage. For the prototype machine we used the solenoid valves which are operated with 240VAC.

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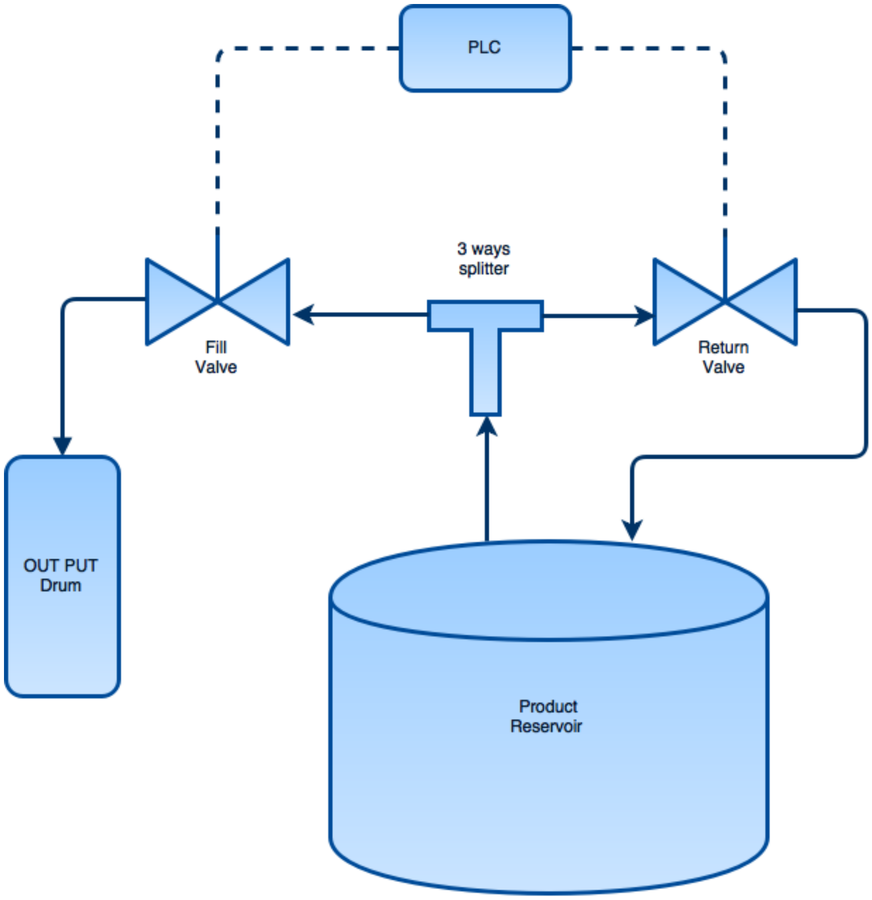

Figure 1: Core mechanism flow diagram and command

4.4 Calibration and Calculation

4.4.1 Calibration

In order for the load cell to measure the weight correctly, it was calibrated. By utilizing the standard weight of 20 Kgs, we set the PLC to store the weight data, and use this memory as a reference of weight then interpolate the analog input into the scientific measured mass.

The signal from load cell is in mV, due to the fact that load cell is a strain gauge, bridge type. Hence the voltage differential across the bridge is very small. However, the PLC take analog input as 1-10V, therefore we amplify the signal. By using the IC - INA128(P), we can vary the circuit gain of the signal by simply changing the bias resistor. The resulting signal can be verify using oscilloscope and signal generator.

4.4.2 Calculation

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It was imperative that the main frame be able to support the weight of the components. Therefore CAD model of the frame was subjected to a FEM analysis using NX Nastran solver. The governing equation where the loading equation and bending moment, in this frame, the initial conditions were the simple beam with two fixed supports.

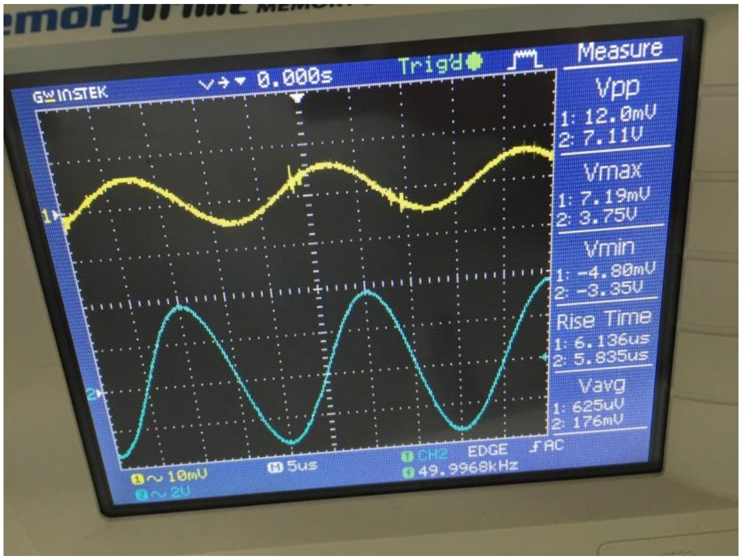

Figure 2: Oscilloscope readings

The signal from the load cell was in the range of 1-10mV, but the PLC required the analog input of 0-10V, hence the need for the signal processing circuit. By using the IC INA128P (Figure 2), we amplified the signal from mV to V range. The gain of the circuit use is 500. Achieved the use fixed-value bias resistor.

Gain G, can be calculated by this equation [9]:

$$G = 1 + \frac{50\ k\Omega}{Rg}$$

Once the signal is in 0-10V range, the PLC still has to process it into a meaningful data. Inside the PLC, the authors have utilized the linearization and scaling to convert the signal into Kilograms reading. In scaling process, we refer to the load cell specification, with its upper limit as our scaling limit.

The errors encounter in the experiment can be traceback, since the amplifying circuit is constructed from a solderless prototype bread board, signal interference is inherent. Therefore

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the accuracy of the machine is significantly contributed by the signal amplifying circuit and its cables.

4.4.3 CFD - computation fluid dynamic and filling time

The CFD calculation was done to ensure that the effect of water hammer was minimal, and the response time of the system was acceptable. The flow in pipe system was governed by Bernoulli equation, although flow was obviously in a turbulent model, this equation provided the initial condition of the pipe system.

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$$

The CFD calculation was done by Solid Work Flow Simulation, the authors had the piping and valve model in Solidworks. The CFD set up at both pipe end as inlet and outlet, with the pipe served as adiabatic wall, and the whole pipe system was a control volume. The equation governing the simulation was the Reynold's average, Navier-Stroke (RANS), The Reynolds average Navier-Stoke equation [13]:

$$\rho\bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = \rho\bar{f}_i + \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \mu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \rho\overline{u_i' u_j'}\right]$$

We observed, the velocity vector, and the linear momentum of the flow, and the simulation results conclude that the effect of the water hammer can be negate by optimizing the time differential of valve opening in a precise manners. Such that when the filling valve is about to close, the return valve must open before. Thus minimized the water hammer effect the flow rate obtained in the simulation can also be used for future expansion/upgrade of the machine.

5. EXPERIMENTAL TRIAL

5.1 Initial Condition

The trial was designed around the repeatability of the machine, after filling there was a weight verification procedure using a standard weight. It was imperative for the machine to be in "Ready state" when prepare for the real life application in factory. Hence, the ready state is always ready to fill the gallon.

The trail consisted of filling a single drum or a series of drum, three or five, then weight verification. Everything was recorded on a camera.

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Figure 3: Experimental Setup

5.2 Experimental Results

PLC integration test has succeeded. The PLC has the control of the entire filling process. User only needs to provide the "Fill" input command. The PLC instantaneously provides output action in response to the input. Feedback from load cell is precise but there is some off-set value to encounter. See the Figure 3.

Inevitably, errors are bounded to happen. This is no exception. There are errors in our system as evidence from the result. However, to counter the error, off-setting the values are currently the immediate solution. With off-setting values of the logic, the error has reduced to acceptable level (approximately 3%).

Some improvements can be made during the test. For example, ability to operate with any type of liquid (i.e. different density). Another improvement such as accuracy of instrumentation amplifier can also be made using shield wire.

Refer to table 1 below, are the raw data of the trial run.

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Nr.	Description	Filling Time	Expect (kg)	Actual (kg)	Drum Wei.	Error (Kg)	% Error
	Components	N/A	N/A	N/A	N/A	N/A	N/A
	Dry Run	N/A	N/A	N/A	N/A	N/A	N/A
1	1-Cycle	23.91 sec	10	9.61	1.53	1.92	19.20
2	1-Cycle	24.0 sec	10	9.61	1.53	1.92	19.20
3	1-Cycle	25.16 sec	10	10.15	1.53	1.38	13.80
4	1-Cycle	23.69 sec	10	9.53	1.53	2	20.00
5	1-Cycle	22.55 sec	10	9.66	1.53	1.87	18.70
6	3-Cycle	85 sec	10	9.63	1.53	1.9	19.00
			10	9.6	1.53	1.93	19.30
			10	9.6	1.53	1.93	19.30
7	3-Cycle	85.1 sec	10	9.4	1.53	2.13	21.30
			10	9.5	1.53	2.03	20.30
			10	9.4	1.53	2.13	21.30
8	3-Cycle	106 sec	10	9.78	1.53	1.75	17.50
			10	9.54	1.53	1.99	19.90
			10	10.38	1.53	1.15	11.50
9	3-Cycle	90 sec	10	9.5	1.53	2.03	20.30
			10	9.58	1.53	1.95	19.50
			10	9.42	1.53	2.11	21.10
10	3-Cycle	84 sec	10	9.5	1.53	2.03	20.30
			10	9.46	1.53	2.07	20.70
			10	9.5	1.53	2.03	20.30
11	3-Cycle 15 Kg	117 sec	15	13.6	1.53	2.93	19.53
			15	13.6	1.53	2.93	19.53
			15	13.37	1.53	3.16	21.07
Nr.	Description	Filling Time	Expect (kg)	Actual (kg)	Drum Wei.	Error (Kg)	% Error
12	3-Cycle 20 Kg	156 sec	20	17.6	1.53	3.93	19.65
			20	17.6	1.53	3.93	19.65
			20	17.57	1.53	3.96	19.80
13	3-Cycle off-set	228 sec	25	24.4	1.53	2.13	8.52
			25	23.99	1.53	2.54	10.16
			25	24.5	1.53	2.03	8.12
14	1 Cycle offset	1.10 sec	25	24.0	1.53	2.53	10.12
15	1 Cycle offset	1.09 sec	25	24.6	1.53	1.93	7.72
16	1 Cycle offset	1.12 sec	25	25	1.53	1.53	6.12
17	1 Cycle offset	1.08 sec	25	25.6	1.53	0.93	3.72

Table 1: Experimental Result

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Weight Verification, this process served to verify that the machine, stopped filling at our desire weight measure. The electronic scale was calibrated from the government's office of standard system. Refer the figure 4.

Figure 4: Weight Verification Procedure

6. RESULTS AND DISCUSSION

6.1 Problem solved

From the experimental trials, we have had the record of the consistency in the amount of filling liquid into the container considering the off-set error of the measurement value. The consistency of the machine filling volume average is 95%. The error of 5% is considered as quite high compare to the industrial standards which usually are less than 1%, this is due to the inaccuracy of the signal transfer - interferences, error from the amplifier circuit and excitation source of power supply.

Compare to the observed manual process line at the factory, we calculated the cost reduction of approximately 67%, calculated from the process cost per drum. The result demonstrated the benefits in terms of reduction in skilled labour and error of the filling product.

By neglecting the off-set value of the measured mass, from the different filling amount trials, we found out that the machine has the maximum error limit of about 5.094% and minimum of 3.274%. The larger fill volume, the lower percentage error in the accuracy. The off-set value is considered as consistence and obtained from the experimental data, this is due to the load cell signal processing in the PLC.

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This machine, obviously, minimized the human error of unnecessary contamination of the process line. Increasing the hygienic practices, thus ensuring the safety standard for the consumer and boost their satisfaction.

6.2 Lessons learned

Applying the off-the shelf components to new tasks might require some modification and often quite difficult. However, comparing to design a specific piece of equipment and custom-made each of them can take a long time and cost a huge part in our capital.

Cheap electronic components can cause a huge error - this is because most of the IC and some other electrical equipment have high tolerances, including the lack of shield or signal noise cancellation caused us to face with such a huge necessary error.

Mechanical parts might seems to be the easiest to deal with, however, with the limited tools and supply we have, simple tasks can be complicated. We tried with the aluminum frame prior to the aluminum profile system, getting two pieces parallel vertically was a mission impossible.

In this project, authors have tackle several challenges, the first being the fact that we must design the amplifying circuit of our owns. To suit our application. And deeper challenge is lies in the procurement of the IC itself, in Thailand the INA128P is very difficult to obtain. Another challenge in this project is to manufacturing the frame, since all the works has to be done by hands. The quality of the workpiece is vary, the angle of the frame can be subject to different factor. So the authors eliminate this problem by using the extruded aluminum profile. Wiring of both electrical circuit (24V, 220V) is also proved to be a great learning curve for all involved. The relays socket, power supply and output/input switch must be correctly wire and color coded. Otherwise it will cause further works.

6.3 Results

From the experimental trials, the machine shows function up to its promises. However, there are still needs to tweak and redesign certain components such as the amplifying circuit. According to the results, it is evident that the machine has process precision but not accuracy. This is due to the error in gain calculation and signal interference of the load cell amplifying circuit. Refer to the Table 3A, We can track the increase in accuracy as the expected weight increase. Therefore the objective is fulfilled. Further improvements on the machine design and accuracy are highly recommended, because the huge cost reduction in automation technology will help a lot of SME business.

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7. Conclusion

In all, the objective of this project is fulfilled, which is to create a working prototype of user-friendly filling machine. The machine is yet to be perfect but it still works within acceptable limits. There are some improvements that can be made for further development.

We have learnt a lot from this project as the team must came up with creative solutions to tackle the arising problems. The team also realized that procuring the right equipment is not easy task. The team has also taken a look in financial aspect as an effort to keep the cost in limits.

Through a series of calculations, the solution provided to this factory could result in benefits in terms of cost due to errors and skilled labor wages up to 67%. This is advancement for SME companies, allowing them to streamline the processes, similar to larger firms in the market.

This project also provided a practical work for many subject such as industrial automation system, mechanical design, engineering economic or even automatic control.

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