Development of a Dough Dividing Machine with Counting Ability for Local Bakeries in Sri Lanka

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Abstract— *Bakeries often require the assistance of machines in order to effectively and efficiently produce baked goods to supply to customers. Yet in countries like Sri Lanka, most bakeries still carry out the dough dividing process manually. Importing a dough dividing machine is expensive due to the added tax and delivery charges. This report looks into the development of a dough dividing machine that has counting ability for local bakeries in Sri Lanka. Some components of this model machine are different to those of the machines available abroad and this is to create a more cost-effective machine. The calculations were carried out for a 2/3rds scaled down version of the actual machine, and included calculations and dimensions for the hopper, gears, shafts, coupling, chain & sprocket and information on the selection of the motors and bearings. SolidWorks software has been used to design and carry out finite element analysis on the machine components. In order to count the dough balls produced, Arduino IDE software has been used to write the code for the counting mechanism, which uses an Arduino UNO along with an IR sensor and display to count and display the dough balls that leave the exit of the rounding plate. The ideal speed to rotate the rounding plate was estimated through data obtained from experimentation.*

Keywords— **Dough Dividing Machine, Bakeries, Counting Mechanism, Rounding Mechanism, Sri Lanka**

I. INTRODUCTION

In the present times, with the advancement in machinery and products, the world now automates (fully or partially) most of the industrial work that was manually carried out in the past decades. The same can be said for the food industry. The need for higher quality hygienic food (for customer satisfaction) as well as for it to be cost-effective and efficient have become the main goals. Bakeries around the world now carry out their baking processes with the aid of machinery, yet in countries like Sri Lanka, the process of separating the dough into dough balls to bake buns is usually carried out manually; kneading the dough by hand (or using the mixer) and cutting it off into the necessary sized parts. This is time consuming, as well as labor intensive, and can often cause the efficiency of the work to decrease due to tiredness and monotony. While this is the case, dough dividers are quite expensive and for countries like Sri Lanka with small bakeries all around the country, spending so much on something that can be done manually may seem uneconomical. Manufacturing the machine locally will allow it to have a lower cost so that local bakeries will be able to take a step forward into the new automated world and increase their efficiency and production, while lowering the cost for manual labour. The process of dividing the dough into small balls manually by hand causes the buns to vary in size and so may not be the most effective, but by using a dough dividing machine, all the dough produced will be cut into precise sizes, ideal for batch productions. Keeping track of the number of dough balls produced when separating them manually causes room for error, therefore, incorporating a counting mechanism into the machine is a new addition.

II. LITERATURE REVIEW

Most of the dough dividing machines are aided by electric, hydraulic or pneumatic systems to either press the dough or operate the cutting mechanism. Sampath et al. designed and fabricated a hydraulic dough divider that includes a two stage telescopic cylinder that compresses and distributes the dough in the first stage and as the second stage, uses a blade to cut through it. Using SIM-H to design and simulate the machine, they were able to manufacture the actual product. A 4/2 directional control valve was used to control the levers of the machine (Sampath *et al.*, 2019)**.**

The type of dough worked with is the main factor to consider when choosing from the several varieties of dough dividers that are offered on the market. The amount of effort required and the kind of dough or pastry needed to be divided and sorted should always be taken into consideration when selecting a dough divider (ATS, 2022). There are different types of dough dividing machines, some of which are: dough dividers with pneumatic/motor controlled blades, dough dividers with press cutters, dough dividers with dividing drums as well as different machines that assist in the process of dough dividing, such as conical rounders, intermediate provers, and dough weighting systems (ATS, 2022).

Almost all kitchen appliances that come in contact with food are made of stainless steel. There are different grades of stainless steel that can be used in the industry; Grade 303, 304 and 316 (Jullien, 2003). Grade 303 stainless steel is highly machinable yet it is not ideal for machines that interact with food. Grade 304 on the other hand is the most popular grade of stainless steel for use in kitchen appliances and equipment. If the food in question is not acidic in nature, then using grade 304 stainless steel is an economical choice. For cutlery and machines that require a smoother finish and require corrosion levels to be minimum, grade 316 stainless steel is the ideal type to be used (Jullien, 2003).

Some common equipments that are used for dough dividing are rotary/extrusion, piston, ram and knife, pocket and stress-free dividers (Marsh, 1999). A single or double screw extruder (one shorter than the other to help the dough move towards the end of the cylinder) can be incorporated into the dividing process in order to push the kneaded dough through to the opening where the dough will be cut/divided into balls (Saleh et al., 2017). This is much more effective than using a piston or plunger to push the dough into the head of the cylinder to be cut, since the dough may intervene with the components and cause the machine to break down.

For the counting mechanism, IR sensors are used as motion detectors and this coupled with an arduino system along with a display will allow objects that are moving in front of the sensor to be count and displayed for the user. The IR sensor contains an emitter (IR LED) and a detector (IR photodiode); the emitter emits light using the LED and once an object moves in front of it, the light bounces back and is detected by the IR photodiode. The photodiode's resistance and the output voltage changes according to the IR light received back. The arduino will detect this change in voltage and increase the count displayed on the screen by one (Adnan, 2021).

III. METHODOLOGY AND EXPERIMENTAL DESIGN

In order to design the dough dividing machine, its main components were identified through the aid of other existing literature on similar machines. The main components of the machine that were essential for it to work efficiently were the hopper, extruders, chain & sprocket, pulley/coupling system, motors, rounding plate, counting mechanism, gear system, shafts and bearings. The dimensions for these components were found through calculations and a design was developed through the SolidWorks modeling software as shown in Figure 1.

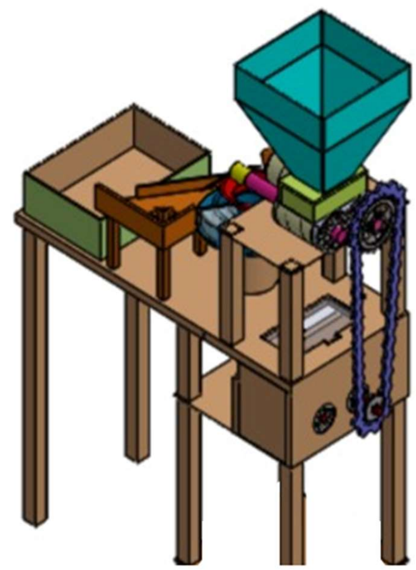

Figure 1: CAD Model of the developed system

In order to verify that the components were safe, finite element analysis was carried out on the designed components under loading.

Once this was finalized, the fabrication process was started. The components were either purchased from shops (motors, bearings, chain and sprocket, etc.) or manufactured in the workshop (hopper, rounding plate, extruders, etc.). After assembling all these components, testing was carried out to find out issues with the machine, to optimize it and to evaluate its performance.

The power transmission processes in this machine are as follows: when the motor runs with a given speed (in this case 65 rpm), the coupling system must be able to transfer the power at the same speed. This power is then transferred from the pinion to the gear which will increase it to the desired speed (130 rpm). This is connected to a chain and sprocket, which will transfer the power with a speed reduction to around 30 rpm into one of the extruder shafts, which will be able to give out 1 dough ball every 2 seconds. These extruder shafts have two one-to-one ratio gears, so that both the extruders will rotate at the same speed, pushing the dough forward to be cut. The cut dough will fall into the rotating plate which will be rotated by connecting it to a small motor. The speed of the rotating plate can be changed by adjusting the speed of the motor through a light dimmer. In order to find the ideal speed for the rounding mechanism to produce the most rounded dough balls, the plate would be rotated at a chosen set of speeds to observe which will produce the dough balls with the most desired shape.

The gearbox may not be a necessary component for the scaled down model since a pulley can transfer the required power and torque straight from the motor to the extruders, but in the actual machine, the high torque required makes it a necessity for the power to pass through a gearbox for the safety of the machine. This is why a gearbox is incorporated for this model. The presence of a chain and sprockets mechanism instead of another pulley system is to ensure that a high torque can be transmitted without slipping.

IV. RESULTS

A. *Motor Selection*

As this was a model, the motor selected was according to the scaled down speed needed for the machine. The main motor selected was a wiper motor that could hold the maximum torque produced by the gears when they rotated at the lowest speed. The motor had a speed range of 45-65 rpm.

Initially, an AC motor with a maximum speed of 900 rpm was purchased. In order to reduce the speed, a light dimmer was incorporated; by varying the voltage received, the speed could be either increased or decreased. But after carrying out testing of the motor, it was seen that the required torque could not be transferred from this motor. Therefore, it was used to turn the base plate of the rounding mechanism instead.

B. *Hopper Dimensions*

The hopper is what holds the dough and lets it pass through to the extruders to be cut into round shapes. Dimensions of the hopper were determined by deciding that the hopper should be able to hold 2 kg of dough at a given time. The material used to manufacture the hopper was Stainless Steel grade 304 as the dough would be in contact with it.

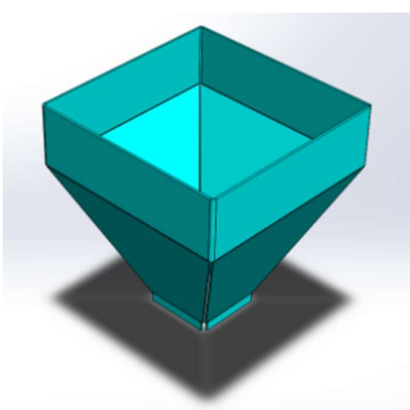

Figure 2: 3D Design of Hopper

C. *Extruder*

The extruders were manufactured using Stainless steel grade 304. Doughnut shaped rounds were cut and welded together in a spiral shape onto a shaft to create the extruders. Two extruders were incorporated into the machine, one shorter than the other to aid in pushing the dough forward.

D. *Gear Calculations*

The gear calculations were carried out to find the number of teeth, diameter and module of the gears and to test whether the material used for them (cast iron) was suitable, calculations for tangential, dynamic, static and wear tooth loads of the gears were carried out.

Table1: Gear Summary

Gear Wheel	Module (mm)	No. of Teeth	Diameter (mm)	Center Distance (mm)
Gearbox Pinion	2	50	100	75
Gearbox Gear		25	50	
Extruder Pinion	2	36	70	70
Extruder Gear		36	70	

E. *Shaft Diameters*

Bending moment calculations were carried out to find the required diameters of the shafts needed to hold the gear system and the extruders. The diameters selected were 15 mm shaft for the gear assembly and 25 mm diameter shafts for the extruders.

F. *Chain and Sprocket Selection*

In order to transfer the power from the gears to the extruders and to reduce the speed from 130 rpm to 30 rpm, a chain and sprocket mechanism was used. The dimensions for the sprockets and chain length were taken from a selection catalogue (Chaparral, 2021)

G. *Coupling Calculations*

In order to connect the motor to the gear system, a coupling was designed with the necessary dimensions. Equations to obtain these values were taken from Khurmi's 'Textbook of Machine Design' (Khurmi, 2008).

H. *Counting Mechanism*

In order to count the produced dough balls, the counting mechanism system was positioned right at the exit of the box. The arduino circuitry was connected as shown in Figure 3.

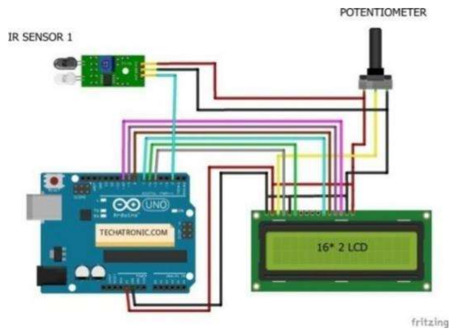

Figure 3: Counting Mechanism *(Adnan, 2021)*

I. Rounding Mechanism

The spiral boarders and the covering of the rounding mechanism were 3D printed using PLA to the required size.

The final assembled model is shown in Figure 4.

Figure 4: Assembled Model

J. Bearing Selection

According to the calculations and the sizes of the components associated with the shafts, the bearings selected were 4 of the 6002 sealed type for gearbox shafts and 3 of the 6305 sealed type for use with the extruders. The sealed types of bearings were selected for longer life and thus to prevent dough and other dust from accumulating and damaging the bearings over time.

K. Finite Element Analysis

FEA analysis was carried out for the gear and shaft bearing the greatest loads of the gearbox. All maximum stress values obtained were below the yield strength of the materials and both the components had a factor of safety greater than 1. The results were obtained for the stress, displacement and strain analysis.

The FEA for the gear wheel had a maximum stress value of 96.52 MPa. This did not exceed the yield strength of the gear material, and therefore ensured that the gear was safe under maximum loading. The maximum stress value for the shaft was 1.02×10^3 MPa and showed that it too was safe under loading.

L. Varying the Speed of the Rounding Plate

The main aim of the rounding mechanism was to produce well rounded dough balls and so the right speed would be needed to produce the desired shaped balls. In order to test the most suitable speed at which the rotating plate should be turned in order to produce well rounded dough balls, 5 different speeds were selected: 50 rpm, 75 rpm, 100 rpm, 125 rpm and 150 rpm.

With each of the 5 speeds, the machine produced 20 dough balls from the same dough mixture. For the 5 speeds stated above, the shapes of the dough balls exiting the plate were categorized into 3 shape types: A, B and C, as shown below; A being the ideal shape as well rounded, while C is the least acceptable.

Figure 5: Shape of Dough Balls (a) Shape A, (b) Shape B and (c) Shape C

At each of the speeds tested, the weight of the dough balls produced was checked using a weighing scale. The weight of the dough balls remained roughly 20 g. This was because the speed of the dough coming out of the extruder cone and the speed of the rotating blade remained constant. Therefore, the weight of the dough balls cut would not change.

Figures 6, 7 and 8 show the number of dough balls with each shape produced at the 5 speeds used.

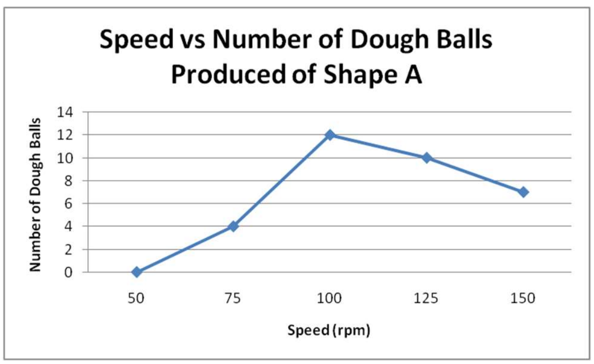

Figure 6: Graph of Speed vs. Number of Dough Balls Produced of Shape A

Figure 6 shows that the ideal Shape A dough balls were produced at a speed of 100 rpm and the least at 50 rpm.

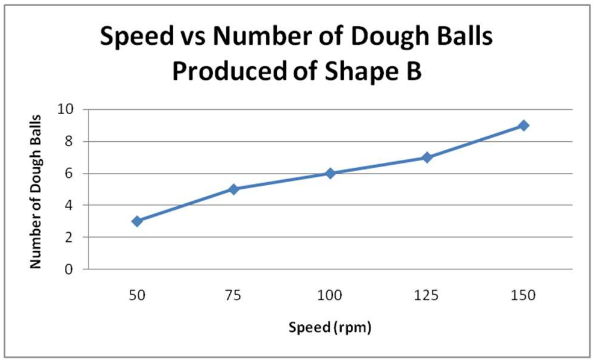

Figure 7: Graph of Speed vs. Number of Dough Balls Produced of Shape B

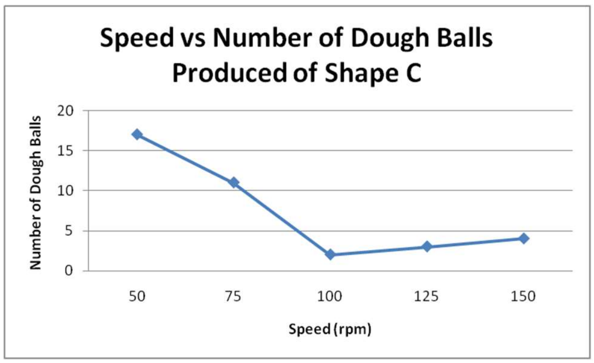

Figure 8: Graph of Speed vs. Number of Dough Balls Produced of Shape C

Since Shape A is the ideal, the highest numbers were produced when the speed was 100 rpm, while the least preferred Shape C dough balls were produced in lowest number at 100 rpm. This concludes that the most appropriate speed for the rounding plate to be turned is at 100 rpm.

M. Payback Period

The machine built for this project is a scaled down model of the dough dividing machine, therefore it is difficult to calculate the payback period with the amount spent on building the model. Theoretically, if we were to consider building the full scale machine, the cost of the machine would roughly be Rs. 300,000. This is considering the high inflation rate of the country's economy and the high cost of components in the country as of November/December of 2022. The profit earned from incorporating the machine into the bakery process is estimated to be Rs. 15,000 per day if the bakery produces 1000 buns per day with a profit of Rs. 40 from each bun and with the machine working for only 2 hours each day. With the reduced cost of labour and electricity and other factors, the payback period was calculated as follows:

$$Payback\ Period\ (days) = \frac{Rs.300{,}000}{Rs.15{,}000} = 20\ days$$

This means that the cost of the machine being operated can be covered in just a mere 20 days of working and with only a workforce of 1 person, thus reducing the money needed to be set aside for manual labour. This would make the machine very cost-effective and ideal to be used in bakeries, both big and small.

V. Discussion and Conclusion

The main objective of this project was to design, develop and fabricate a dough dividing machine with appropriate components and mechanisms for use in local bakeries in Sri Lanka. By reviewing literature, the main components of the machine were found and with further analysis, the rough dimensions of the components were decided. Through this, a conceptual model was designed and the necessary calculations were carried out. A model scaled down to 2/3rds was manufactured rather than the full scale machine due to the economic situation of the country. The finalized 3D model was designed using SolidWorks 2021 modeling software and the same was used to carry out the finite element analysis on the gears and shafts of the machine. The results have shown that the components were safe under the maximum loading that it held. Arduino IDE software was used along with an Arduino UNO board, IR sensor and an LCD display for the counting mechanism.

In the model built, incorporating a gearbox was not necessary as the torque produced from the motor could be transferred with just a pulley. But when the actual full scale machine is built, the presence of a gearbox is essential as the torque needs to be transferred to the components safely. To ensure that all components of the actual machine are present in our model, we carried out calculations and manufactured the gearbox as well.

Finding the most suitable motor for the applications was difficult due to the unavailability of components in the market in the present day. Our idea to incorporate an elbow mechanism to transfer power at a 90 degree angle (rather than using a bevel gears or a separate motor) was short lived due to its inability to withstand the vibrations of the machine. As future work, this machine could be built to the original scale and with quality materials to be sold to the food industry.

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ABBREVIATIONS AND SPECIFIC SYMBOLS

3D – 3 Dimensional

FEA – Finite Element Analysis

IDE – Integrated Development Environment

IR – Infrared

LED – Light Emitting Diode

PLA – Polylactic Acid

RPM– Revolutions Per Minute

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