Design of Bread Packaging Machine for Small Scale Bakeries

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Abstract
This research study was undertaken to come up with a design of a low cost bread packaging machine suitable for use by small scale bakeries which handle about 3000 to 5000 loaves a day, to improve on the prevalent manual bagging practice. An evaluation of the literature pertaining to bread packaging machines and their components was done to come up with a robust design. Three design concepts of the machine were generated, and an improved heat press packaging mechanism was further developed into a detailed design. An assembly and part drawings were also done to enable manufacture in future. An economic analysis was also done to establish the cost, which was found to be about $5 900 to make the prototype. The design could further be improved on plastic clip closure mechanism for effectiveness. The implementation of this project can have a positive impact on the production scale of small scale bakeries.

1. Introduction
Over the years, packaging has played a vital role in containing and protecting food as it moves through the supply chain to the consumer. It reduces food waste in transport, storage, and innovations in packaging materials, design and labeling provide new opportunities to improve efficiencies (Verghese, et al., 2013). It has become an important element of total product design for long shelf life (Coles, et al., 2003). Packaging is important as it makes sure that product safe and in good condition (Kanimozhi, et al., 2015). Many small to medium producers of bakery products resort to manual production means since the large production machines are too big for their needs. Most bread and other products from small-scale bakeries are not packaged, except wrapped in simple paper or plastic bags to protect them from dust and other contaminants (United Nations Industrial Development Organization, 2004). The trend is to have bread being produced near the consumers for it to be delivered fresh to the customers. As such small scale bakeries are found in various highly populated areas. Mostly, small scale producers use transparent and unprinted plastic bags for packaging.

2. Background
The issue of bread packing seeks to eliminate is too much handling of bread during manual packaging. It was observed that bread is packaged manually by the shop workers. In some shops it is placed on the shelves, with the packs for the customers to pack for themselves. This poses health risks on the consumers of the bread. Also there is need to deal with high defect level during and after packaging such as incomplete seals. Available bakery packaging machines are meant for large scale production of up to 500 000 loaves of bread for example. These are expensive and too large to be used by small and medium scale producers who produce 5000 loaves of bread per day. A bakery packaging system for these producers is necessary.

3. Literature review
In a bakery, bread making process is done through a series of steps which include mixing and kneading the dough, fermentation, division and gas reproduction, molding and baking, as well as slicing and packaging. More human intervention in the last steps of the bread making process led to the realization of this study. Small scale bakers sell
the bread unsliced, leaving the work to the customers. It has also been noted that bread is packaged manually. Food protection is often regarded as the principal function of the package: to protect its contents from all the outside environmental effects (Robertson, 2010). Chemical and mechanical damage can occur to the unpackaged bread. Generally, the food industry and in particular the small traditional bakery industry must deliver to the market high-quality and safe products to satisfy the needs of consumers. At the same time they must adopt to standard and reliable procedures (Denti, et al., 2008). One of the greatest functions of packaging is keeping the product clean and provide a barrier against dirt and other contaminants. Packaging for bread must safeguard the food against physical and chemical damage (e.g. water and water vapor, light oxidation) as well as insects and rodents. Unpackaged bread on the shelf is prone to damage by these factors. Additionally, the material chosen for packaging must not interact with the bread or contain toxic compounds. Packaging can be categorized into four groups which are primary, secondary, distribution or tertiary and unit load. The bread packaging machine to be designed shall focus on the primary packaging. Since there are more units to be packaged, say 5000 loaves of bread the machine will greatly reduce the time for the packaging process. In the modern industries pressure to reduce packaging costs, both of the material and of the packaging operations is increasing.

In the current small scale bakeries there is still much manual handling of food. Bakeries usually focus on the bread making equipment and the packaging process comes as an afterthought. Workers are usually assigned with the duty of manually packing the bread. Manual handling poses health risks on the consumers if it is not done properly. It has also been noted that some small scale bakeries especially the in store bakeries, offer unpackaged bread to the customers. The customers will also have to pack their bread manually and hygiene is usually not considered. For small scale producers in any business to grow they need to improve the quality of their products as well as productivity. Low cost automation can be applied to improve quality and productivity. (Lodha, et al., 2015) agree that Low cost automation comprises the use of standard components to mechanize or automate machines, processes and systems. The low cost automated machines require limited human intervention and thus for operation semi-skilled or unskilled labor is required.

Sealing plays a critical role in plastic packaging. The various sealing methods vary in cost, speed and quality (Cantwell, et al., 2015). Different sealing technologies are applied for the manufacture of flexible packages. These include impulse heat sealing, bar heat sealing as well as ultrasonic and hot air welding.

4. Detailed design process

Using the knowledge from the existing literature in prior sections, the authors generated three different possible concepts to bread packaging for small scale bakeries. Drawings for the possible solutions were done using AutoCAD 2015. Based on functionality, cost and ease of manufacture as important factors heat sealer and trimmer concept design was chosen as it satisfies most requirements for bread packaging by the small scale bakeries. Figure 2 gives heat sealer and trimmer packaging concept which was further developed in the following sections.
The roller, with pack material sealed on one end, is placed vertically above the packaging area. Two rollers keep the rolled package wide open. Bread from one side is moved by a belt conveyor and them pushed by an arm into the packaging material. A heat seal and trimmer then trims the plastic material along the bread. It closes the side of the packaging bread and then makes one end ready to for the next loaf to be packed. Packed bread falls a small distance to another conveyor belt. This conveyor belt transports the bread to a bag closure mechanism particularly the plastic clip machine. After that bread is now ready for secondary packaging. Material selection was done and the necessary parameters for the materials were noted where they were necessary for calculations.

**Design parameters:**
- 5000 loaves of bread per day
- 6 hours of operating the machine are recommended
- 4 seconds of packaging each loaf of bread

**Design of the jaw**
- Sealing temperature: 130 – 140 degrees Celsius
- Pressure: 276 kPa
- Dwell time: 1 seconds

Both jaws will be heating for uniform sealing and cutting. The time, temperature and pressure to produce a good seal are as highlighted above. A heating element and a temperature sensor will be included in the jaw.

\[
\text{Area for pressing} = 0.3 \times 0.005 = 0.0015
\]
\[
\text{Pressure required} = 276000 \text{ Pa}
\]
\[
\text{Force required} = pA = 276000 \times 0.0015 = 414 \text{ N}
\]
Design of pneumatic cylinder

Cylinders convert fluid power into mechanical motion. A cylinder consists of a cylindrical body, closures at each end, movable piston, and a rod attached to the piston. When fluid pressure acts on the piston, the pressure is transmitted to the piston rod, resulting in linear motion.

Force required, \( F \) = 414 N  

Piston diameter (bore) = 50 mm  

Rod diameter = 25 mm  

Stroke = 100 mm  

\[
\text{Area, } A = \frac{\pi b^2}{4} = \frac{\pi \cdot 0.05^2}{4} = 0.001963495
\]

\[
\text{Pressure, } p = \frac{F}{A} = \frac{414}{0.001963495} = 210848 \text{ N/m}^2
\]

\[
\text{Area, } A = \frac{\pi d^2}{4} = \frac{\pi \cdot 25^2}{4} = 0.000490875
\]

\[
\text{Pulling force} = p(A-a) = 210848(0.001963495-0.000490875) = 310 \text{ N}
\]

\[
\text{Flow rate, } Q = A\times\text{stroke} = 0.001963495 \times 0.1 = 0.000196349
\]

\[
\text{Speed on the outward stroke} = \frac{Q}{A} = 0.01178097/0.001963495 = 6 \text{ m/s}
\]

\[
\text{Speed of retraction} = \frac{Q/(A-a)}{} = 0.01178097/(0.001963495-0.000490875) = 8 \text{ m/s}
\]

\[
\text{Power} = pQ = 210848 \times 0.01178097 = 2483 \text{ W}
\]

Type of cylinder mount

A double acting cylinder was chosen for this application. It will have a return spring so that it returns to its original state when not powered. The flange mount is selected for fitting the cylinder to the body or frame of the machine. It is one of the strongest and most rigid methods of mounting. With this type of mount, there is little allowance for misalignment. The cylinder is used in a thrust load application thus a blind end flange should be used.

Rod size

Rod diameter = 25 mm  

Cover inner diameter = 28.125 mm  

Cover outer diameter = 84.375 mm  

Material for the rod is stainless steel which can withstand the heat and does not budge due to the forces that are to be experienced in operation.

Conveyor system

Considering the objective of the bread, each loaf of bread is to be delivered in 4 second.

\[
\text{Speed of the belt} = 400 \text{ mm/second}
\]
Distance travelled by bread = 1500 mm
Estimated distance between two consecutive loaves = 100 mm

**Pulley arrangements**

![Diagram of conveyor components locations]

The pulleys for the input conveyor system will be arranged as shown in Figure 4. Conveyor rollers are used in the bed of a conveyor as support for the conveyed bread. They are also used underneath as support for the conveyor belt so as to keep it tight. The drive pulley drum is mounted on the shaft together with the pulley that is connected to an electric motor.

\[ T_1 = \text{Tension in the tight side of the belt} \]
\[ T_2 = \text{Tension in the slack side of the belt} \]

Slip, \( s_1 = s_2 = 1.2\% \)

Maximum tension in the belt, \( T = T_1 + T_c \) = Stress \times Area = \sigma b t = 2 \times 500 \times 5 = 5000 \text{ N} \)

Mass of the belt per meter length, \( m = \text{Area} \times \text{length} \times \text{density} = b \times t \times l \times \rho = 0.5 \times 0.005 \times l \times 1170 = 2.925 \)

The velocity of the belt, \( v = 0.4 \text{ m/s} \)

Centrifugal tension, \( T_c = \frac{mv^2}{\mu} = 0.468 \text{ N} \)

Rotational speed of the pulley, \( N = 38.66 \text{ rpm} \)

Length of the belt, \( L = 2\pi r + x = 2 \times 2\pi \times 0.1 + 1.5 = 2.756 \text{ m} \)

Power transmitted, \( P = (T_1 - T_2)v = (142.1 - 35.41) \times 0.4 = 42 \text{ W} \)

**Face length of conveyor pulley**

The face length of the pulley is selected based on the length of a standard loaf of bread. It must be wide enough to accommodate the bread and must not allow bread to fall in case it is misaligned. A face length which is 50 mm greater than the overall width of the pulley is used. A standard value of 51 mm is selected.

**Anticipated belt tension of conveyor system**

Belt tension measures the degree to which the conveyor belt is stretched or held taut and is typically measured in pounds per inch width (PIW). Belt tension is applied to the conveyor system by the following sources:

1. Conveyed Load: The weight of the product that is being conveyed produces a resisting force which will fight against the forward motion of the conveyor belt, therefore providing additional belt tension to the conveyor system.

   - Mass of the loaf of bread = 0.75 Kg
   - Weight of the loaf of bread = 7.3575 N
   - Loaves carried per unit time = 3
   - Allow for overload and safety factor = 1.33

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2. Catenary Load: The mechanism designed to support the weight of the conveyor belt in the return section of a conveyor will impact the amount of tension experienced by the pulleys. This type of belt tension is produced by catenary load which is a by-product of the level of catenary sag existing in a conveyor belt. By considering the belt configuration shown above, belt weight per unit length

\[
\text{Allowable weight due to sag} = 0.5 \times 0.005 \times (5 \times 0.3) \times 1170 = 4.3875 \times 9.81 = 43.04 \text{ N}
\]

3. The Take-Up Mechanism: The amount of belt tension on a conveyor system may require belt slack adjustment during installation procedures, normal operation for belt tracking purposes, or for disassembly purposes during maintenance procedures. The term Take-Up refers to a variety of devices that are used to provide adjustment in the amount of belt tension on a conveyor system.

\[
\text{Allowable tension due to take up system} = 50 \text{ N}
\]

Total tension, \( T_1 \) = 49.05 + 43.04 + 50 = 142.1 N

**Outer diameter and shaft diameter of conveyor pulley**

The Conveyor Equipment Manufacturers Association (CEMA) recommends that shafts be designed with a maximum bending stress of 8000 psi (55 MPa) or a maximum free shaft deflection slope at the hub of 0.0023 inches per inch. These variables are used to calculate the diameter of the shaft in the design of shaft section. A 180° belt wrap is found to be suitable for the system. The carried loads are lighter that for most industrial purposes. A removable shaft extends through the pulley, is held in place by set screws and driven by keyways. Contact surface is to be constructed from a cylindrical tube, shell or pipe which allows for continuous full contact with the conveyor belt. The tube is to be lagged with rubber material to reduce the slip of the belt. For the conveyance of the bread the flat face profile is ideal. This configuration also maximizes belt life by providing an even, consistent wear surface.

**Belt selection**

Belt material = single woven cotton belt.
Density = 1170 kg/m³

The pulley will have a lagging of rubber material to increase the contact between the belt and the pulley.

Coefficient of friction between belt and pulley = 0.30
Belt width = 20" = 500 mm

The preferred values for nominal belt widths of 35 to 63 mm thicknesses = 5 mm
Angle of contact = 11/24

**Estimated drum diameter** = 200 mm

Related permitted stress, \( \sigma \) = 2 MPa

**Dimensions of conveyor drum for the conveyor belt**

**Diameter of the pulley**

By using the space considerations of the machine, the standard diameter of the pulley can be taken as 200 mm. This will then be verified using the stress considerations by using the following formula:

Speed of the pulley, \( N \) = 38 rpm
Density of the rim material, \( \rho \) = 7200 kg/m³ for cast iron

Diameter of pulley, \( D = 200 \) mm
Velocity of the rim, \( v = \frac{\pi DN}{60} = \pi \times 0.2 \times 38 \times 60 = 1.433 \text{ m/s} \)

*Width of the pulley*

The width of the belt for this drive mechanism is chosen in the Belt Selection section. Width of the pulley or face of the pulley \( B \) is taken 10% greater than the width of belt

\[
B = 1.10b \quad b = \text{Width of belt} = 500 \text{ mm}
\]

Pulley width, \( B = 550 \text{ mm} \)

*Thickness of the pulley*

The thickness of the pulley rim \( t \) varies from \( 300/D + 2 \text{ mm} \) to \( 200/D + 3 \text{ mm} \) for single belt. The diameter of the pulley \( D \) is in mm.

Thickness, \( t = \frac{300}{200} + 2 = 3.5 \text{ mm} \)

Select standard \( = 4 \text{ mm} \)

*Dimensions of arms*

The pulley is of 200 mm diameter and is therefore made with solid disc instead of arms. The thickness of the solid web is taken equal to the thickness of rim measured at the centre of the pulley face.

Solid web thickness \( = 4 \text{ mm} \)

*Dimensions of hub*

(i) The diameter of the hub \( d_1 \) in terms of shaft diameter \( d \) is fixed by the following relation:

\[
d_1 = 1.5d + 25 \text{ mm}
\]

\[
d_1 = 1.5 \times 70 + 25 = 130 \text{ mm}
\]

The diameter of the hub is appropriate since it’s less than \( 2d \).

(ii) The length of the hub, \( L = 2d = 2 \times 70 = 140 \text{ mm} \)

Which is appropriate according to the standards.

*Conveyor drum summary*

<table>
<thead>
<tr>
<th>Pulley/Core Diameter</th>
<th>200 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finish Diameter</td>
<td>210 mm</td>
</tr>
<tr>
<td>Face Width</td>
<td>550 mm</td>
</tr>
<tr>
<td>Wall/Rim Thickness</td>
<td>4 mm</td>
</tr>
<tr>
<td>Crown/Profile</td>
<td>flat</td>
</tr>
<tr>
<td>Shaft/Axle</td>
<td>70 mm</td>
</tr>
<tr>
<td>Hub</td>
<td>10 mm</td>
</tr>
<tr>
<td>Bore Diameter</td>
<td>70 mm</td>
</tr>
<tr>
<td>Bearing Centers</td>
<td>700 mm</td>
</tr>
</tbody>
</table>

*Design of shaft for conveyor belt*

This shaft will be supported by two bearings at both ends and mounted with a pulley and the conveyor drum. The conveyor drum is for driving the input conveyor belt which moves the bread to the packing mechanism. The pulley is keyed to the pulley for driving the shaft via a v-belt using an electric motor.
Design of Shafts on the basis of Rigidity

\[ \frac{T}{J} = \frac{G \cdot \theta}{L} \quad \text{or} \quad \theta = \frac{T \cdot L}{J \cdot G} \]

\( \theta \) = Torsional deflection or angle of twist in radians,
\( T \) = Twisting moment or torque on the shaft,
\( J \) = Polar moment of inertia of the cross-sectional area about the axis of rotation,
\( G \) = Modulus of rigidity for the shaft material = 84 GPa
\( L \) = Length of the shaft = 600 mm

Torque transmitted by the spindle,
\[ T = P \times \frac{60}{2\pi} N = 2000 \times \frac{60}{84 \times 10^3} \times 0.0023 = 50.26 \text{ Nm} \]

\[ \frac{T}{J} = \frac{G \theta}{L} \]

\[ J = \frac{TL}{G \theta} \]

\[ \frac{\pi}{32} \times d^4 = \frac{502600 \times 600}{84 \times 10^3 \times 0.0023} \]

\[ d^4 = 16 \times 10^{-6} = 63 \text{ mm} \]

Select standard diameter = 70 mm

The Design of Shafts on the basis of Rigidity gave a higher value. This is stronger for both conditions and will be used in the design. So the diameter of the shaft is to be 70 mm.

Bag closure

A twist tie mechanism is used or the bag closure. This option is the cheapest and the machines are readily available. For this project, the plastic clip machine is recommended to be fitted at the end of the output conveyor system. For this machine, no design is required as much work has already been done. It automatically senses the bread and closes the package with a plastic coated wire.

Locus for the control arms

The control arm is to push the bread from the conveyor belt into the package. It is required that it applies a force that is just enough to push the bread at a higher velocity than it has on the belt, but also less to damage the bread since it is delicate. Adjustments are made to the usual slider crank mechanism. The arm is to move forwards and upwards while in doing so must not interrupt the oncoming bread.

![Figure 5. Locus of controlled links](image)

A – Center of rotating disk
B – Rotates about A and is connected to a link arm
C – Constrained to slide in the path as shown. Connected to a pushing plate CD
D – Moves the bread into the package.

Control system

For the machine to operate effectively, an electric control system will be added. There will be various sensors from the machine that will feed to a control unit. This then sends signals to the parts on the machine so as to regulate the parameters such as speed, temperature and pressure. Major controls to be achieved are:

- The conveyor belt is to move at a constant speed.
- Rotating disk for the arm is also to rotate at uniform speed.
The jaw movement is to be operated by a pneumatic cylinder. It moves when the bread is in the packaging material, dwells for 1 second, then move back to the original position.

The packaging drum rotates only when the bread is to get into the material. It is to be rotated by a motor of which the start and stop can be controlled.

Temperature of the jaw is to be maintained at about 130°C which is optimal for sealing the packaging materials.

Cost Analysis
Total cost of the bread packaging machine components was found to be US$5010 and cost of installing the machine was US$900, making it a total of US$5910 to put in place this facility. Considering the average daily production of 5000 loaves of bread and the cost of the bread which is $1 it is possible for the small scale bakeries to budget for and purchase a bread packaging machine.

5. Recommendations
Although most small scale bakeries offer unsliced bread, a slicing mechanism can be included in further designs of the machine. The electric control system of the machine could be designed carefully and modeled in some software programs such as MATLAB. The machine is to be purchased with a bag closure machine and a plastic clip machine is recommended. Three phase electric power is also required in order to power the electric motors for the conveyor systems. Plastic to be used for packaging should be printed and sealed on one end. If not sealed, a mechanism of sealing the packaging material should be included before the packaging process. A self-cleaning system could be fitted so that this is not done manual. This component can clean continuously and there will be no down times for machine cleaning. The jaw is subjected to high temperatures and thus should be secured so there is no human interaction for safety reasons. It is recommended that bread is placed directly from the oven and a system has to be designed to minimize manual handling of the bread. This system should place the bread at approximately the same distance. For the dispatch conveyor belt, there is need for a means of removing the packed bread from the conveyor. This can also be automated and secondary packages produced. Adjustments should be possible for the pressure, temperature and dwell time of the jaw which heats, presses and trims the packaging material.

6. Conclusion
The machine reduces defects incurred during packaging and is faster than having people packaging bread. If the design is implemented and works properly, the small scale bakeries will increase their production. The design and fabrication of this packaging machine is fairly cheap and enables a simple unit lay out. Efficient sealing and bag closure mechanism can be easily achieved, and so is full automation to minimize human intervention during operation. To further lower the cost, locally available materials were recommended to lower the manufacturing costs. Further studies could be done to reduce the weighty aspect of the current design to improve on robustness.

References


Biography

Ignatio Madanhire graduated with a PhD in Engineering Management at the University of Johannesburg, South Africa, he is also a Senior Research Associate. He is also a lecturer with the Department of Mechanical Engineering at the University of Zimbabwe. He has research interests in engineering management and has published works on cleaner production in renowned journals.

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