# Design of a small scale cereal packaging machine suitable for developing countries

**Tawanda Mushiri**
D.Eng. Student; University of Johannesburg, Department of Mechanical Engineering, P. O. Box 524, Auckland Park 2006,
South Africa.
tawanda.mushiri@gmail.com

Lecturer; University of Zimbabwe, Department of Mechanical Engineering, P.O Box MP167, Mt Pleasant, Harare

**Charles Mbohwa**
Professor and Supervisor; University of Johannesburg, Auckland Park Bunting Road Campus, P. O. Box 524, Auckland Park 2006, Room C Green 5, Department of Quality and Operations Management, Johannesburg, South Africa.
cmbohwa@uj.ac.za

## Abstract

Many food shortages which are being encountered in developing countries are due to lack of effective packaging which results in food loss. Packaging machines manufactured in developed countries are highly automated which make them incompatible with the capacities handled in developing countries. Considering a number of concepts, the selected one is a small scale cereal packaging machine which has a capability of sealing 1kg of any cereal per minute.

## Keywords
Packaging, cereal, machine, auto cad, design, developing countries

## 1.0: Introduction
Packaging is the science, art, and technology of protecting products for distribution, storage, sale and use (Soroka, 2002). It helps to ensure quality and safe conveyance. According to Stewart (1995) pointed out that the basic function of food packaging was to preserve product integrity by protecting the food against possible damage from climate, bacteriological and transit hazards. Packaging machinery is one of the most helpful machines in production services since it is essential to most food industries and other companies. Packaging mostly done by small scale entrepreneurs through the use of conventional methods is very laborious and time consuming. Many may wonder how many packets someone using a simple balancing weight to weigh the contents and a lighting candle to seal the package will produce at the end of the day. This research presents an attempt to design a packaging machine for a small scale businesses in developing countries as a cheaper and more efficient alternative of food packaging machinery.

### 1.1: Background
Many leading packaging machinery manufacturers which have global sales and facility networks at their disposal are focussing on producing supplementary automated and faster machines which are incompatible for the capacities handled by small scale producers in developing countries. At the same time these machines are sold at high cost, though purchasing them may not be an issue but after sales service and maintenance is also a limiting factor (Manalili et al, 2011). A packaging machine should reduce time and labour inputs, increase the rate of production and consequently improve profit returns for the benefit of small scale producers and also for the reduction of cereal losses since packing improves safety and quality.

## 1.2 Problem statement

Some of the uprising entrepreneurs are facing limitations on their goal fulfilment of starting a packaging business due to high cost of packaging machines and packaging itself. Farmers are experiencing losses in transporting their crops from farms to cities and towns for sale to large packaging companies.

## 1.3 Objectives

- To design a machine that operates on simple mechanical principles for ease of operation and maintenance.

- Design a machine that cost approximately US $300.

- To design a durable machine by proper material selection that can last more than 5 years.

## 1.4 Justification

The packaging machine will be purchased at lower cost and at the same time, there will be need for less human manpower since the design will be automated so there are no losses incurred in paying many employees. In general, it will help lift the marketing growth of developing countries since small and medium scale companies make the backbone of the economy. Supply of food is increased since packaging helps to reduce losses.

## 2.0: Literature review

### 2.1: Introduction

Packaging refers to the technology and material for enclosing or protecting products for distribution, storage, sale, and use (Soroka, 2002). According to Concise Oxford Dictionary (Tenth Edition), Cereal is a grain used for food which is grown as an agricultural crop. It helps to ensure quality and safe conveyance of packed products. Food packaging is vital; the package is responsible for serving as an unswerving block between the product and impending contaminants from the outer environment. Effective packaging strengthens shelf life and protects food from bacteria contamination.



*Figure 1: Picture taken at Mbare Musika, Harare, Zimbabwe showing food exposed to bacterial contaminations*

### 2.2: History of packaging machine

According to www.edis.ifas.ufl.edu/pdffiles/AE/AE20600.pdf, humans consumed food where it was found from the very earliest times. When containers were needed, nature provided shells, leaves and gourds. As time goes on, containers were made from natural materials which includes, knitted grasses, animal organs and tunnelled logs. As ores and chemical compounds gets revealed, pottery and metals were developed, leading to other wrapping methods.

### 2.3: Current packaging methods in Zimbabwe

These methods has been phased out mainly by developed countries through their production of highly advanced packaging machinery though they are still in operation in many developing countries as displayed by a survey carried out at Mbare Musika situated in Mbare location, Harare. These methods include sealing of packets using candle light, plastics as fuel and paraffin stove. The methods though seems cheap, are very hazardous to both the people and environment. Since the marketplace is an almost open place, the roof surrounding the place has almost gone with ages. If in any case heavy winds comes, the whole place can blew up with fire.

### 2.3.1: Sealing using candle light

As cheap as a candle might be, there are many disasters to which the women and also the marketplace are exposed to. The hands as well as the women's body are exposed to fire burns. If it happens that a person has burnt, it's most likely that there will a life loss due to large medicational charges in many developing countries of which these people cannot afford.



*Figure 2: A photograph taken at Mbare Market place, Harare, Zimbabwe showing packets of soya mince sealed using candle light*

### 2.3.2: Sealing using paraffin stove

The burning of paraffin produces a lot of carbon dioxide as shown by the equation:

$$C_{25}H_{52} + 38O_2 \longrightarrow 25CO_2 + 26H_2O$$

Hence for every one mole of paraffin burnt, 25 moles of carbon dioxide are produced and released to the atmosphere.



*Figure 3: Photography taken at Mbare Musika, showing a woman sealing kapenta packets using paraffin stove*

### 2.3.3: Sealing using flame from burning plastics

In this type of sealing, plastics are burnt inside a container in which the flame they produce is used to seal the packets.

Figure 4: A photography taken from Mbare Market place in Harare, Zimbabwe showing sealing using plastics as fuel

## 3.0: Technical specifications
### 3.1: Introduction
These are the design specifications which specify what the design has to do. These specifications are expressed in

terms of objectives and constraints.

### 3.2: Design specifications
#### 3.2.1: Performance
- The machine must package and also seal

- The machine must be automated

- Must be able to operate continuously for long periods

#### 3.2.2: Target Product Cost
- The targeted product cost to be $\leq US\$300$

#### 3.2.3: Materials
Proper material selection will be done in the detailed design and there are no restriction on the type of materials to

be used. Part of material selection will be done in the concept generation. The materials must generally be:

- Corrosion resistant, Absorb shock and impact loading impact and fatigue resistant

#### 3.2.4: Aesthetics and Appearance
- Body parts must, be blended into one another to give the most appealing appearance.
- If possible components must be hidden from sight and the operator must only be presented with the
  necessary input ports and output ports.
- Paint can be used to enhance the appearance of the machine.

#### 3.2.5: Ergonomics
In general, it is the study of people's efficiency in their working environment.

- All machine user interfaces must be positioned so as to provide easy access to machine controls.
- Loading and unloading ports must all be within the reach of the average tall person.

- The outputs ports should also allow the easy removal of packets so as to minimize breakages

## 4.0: Conceptual design

## 4.1: Introduction
The subsequent concepts were generated by consulting patents paying due respect to copyright violations. The idea is to bring out the concept only, without comprising on precision. The concepts are accompanied by brief clarifying notes. The concepts will be considered using suitable criteria to come up with the most appropriate design.

## 4.2: Selected Concept
This concept consists of a hopper from which the contents to be packaged are poured through. The amount of contents into the film is controlled by the rotation of the rotating weight meter just below the hopper. The weight meter weighs the amount of contents at the same time its rotation provides the path of the contents into the plastic film. A pair of rollers below the weight meter forms longitudinal seals between the two meshes of thermoplastic films. The other pair of rollers divide by cutting the completed package from the meshes. The package then falls by gravity sliding through the outlet. The roller width determines the seal thickness.
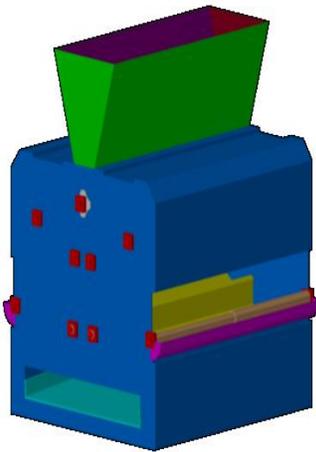


Figure 5: Concept to package cereals

The machine is easy to operate and maintain. With the roller sealer, curved seals can be made which may have a decorative appeal for the customer.

## 5.0: Detailed design analysis

## 5.1: Introduction
The detailed design analysis stage seeks to further develop the concept selected in the previous chapter that it can be designed in the detailed design. At this point the components will be considered individually so the design concept is broken into separate components and each of them is analyzed. The motion generating system will also be preliminarily designed at this stage.
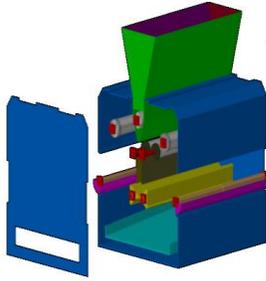
*Figure 6: Selected concept*

## 5.2: Design Procedure

This is where all components of the machine are designed to ensure safety.
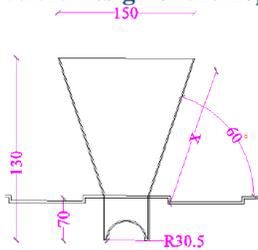
### 5.2.1: Design of the hopper



*Figure 7: Hopper design*

The hopper is the inlet of the contents to be packaged. It should not be big otherwise it will topple the machine or will lead to the need for longer machine length. Requiring that the highest point and the lowest point of the hopper have a difference of 200mm. For intimate mating between the hopper and the frame, distance $x$ should be:

$$xCos\ 60° = 130\ mm$$

$$x = {}^{130}\!/_{Cos\ 60°}$$

$$x = 260\ mm$$

The hopper is to be welded onto the frame for permanent fixing and the welding should be done where it mates with the frame that is at a perpendicular distance of 130 mm. The radial curvature of the hopper just below the frame has a diameter of 61 mm. The weight meter to be fitted on the radial curvature has a diameter of 60 mm meaning there is a 1mm clearance between the curvature and the weight meter to allow the weight meter to rotate freely without the existence of obstacles.

### 5.2.2: Design of shaft supporting the roller in which the plastic slides past
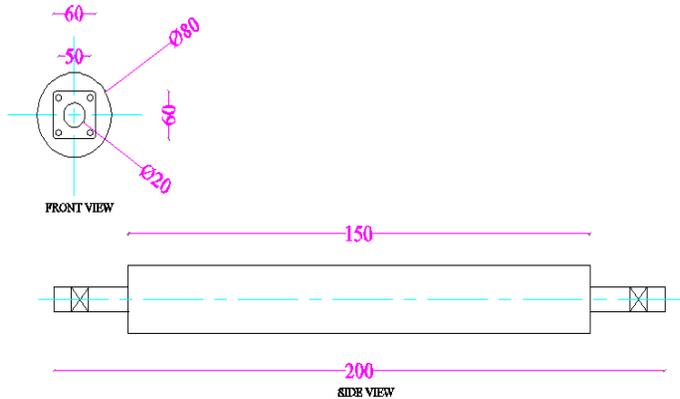
*Figure 8: Shaft supporting roller*

The shaft is mounted on the bearing and it also consists of a roller. The shaft is made of mild steel. According to Indian Standards shown in Appendix 2, mild steel with an Indian Standard Designation 40C8 having carbon composition of which ranges from 0.35- 0.45 and manganese composition ranging from 0.65- 0.90 is suitable for the manufacture of shafts as per IS: 1871 (Part II)−1987 designation (Reaffirmed 1993).The shaft will be stationary so it acts more like an axle. Hence there is bending moment transmission only.

From the Bending Theory,

$$\frac{M}{I} = \frac{\sigma}{y} = \frac{E}{R}$$

Where:

M is the applied bending moment

I is the second moment of area of the beam cross section about the neutral axis

$\sigma$ = stress at a distance y from the neutral axis of the beam cross section

E is the Young's modulus of elasticity of the beam material

R is the radius of curvature of the neutral axis at the section

Hence:

$$M = {EI}/{R}$$

But,
$$I = {\pi}/{64} \times d^4$$

$d$ = the shaft diameter

$$I = {\pi}/{64} \times (20 \times 10^{-3})^4$$

$$I = 4.096 \times 10^{-5} m^4$$

From Appendix 1, the value of E is 200 GN/m² considering the shaft to be made of mild steel and taking the minimum value of the modulus of elasticity.

Therefore,

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$$M = \frac{200 \times 10^9 \times 4.096 \times 10^{-5}}{10 \times 10^{-3}}$$

$$M = 8.192 \times 10^7 Nm$$

M is the maximum bending moment which can be experienced by the shaft without causing it to fail.

Maximum bending moment, $M = WL/4$

Where W is the maximum load which can be sustained by the shaft

$$W = \frac{8.192 \times 10^7 \times 4}{0.2}$$

$$W = 1.6384 \times 10^8 \, N$$

The maximum loading of which the shaft will be exposed to, is far much less than the load it can sustain hence the shaft design is safe. The maximum direct stress which can be sustained by the shaft without causing it to fail is given by:

$$\frac{M}{I} = \frac{\sigma}{y}, \quad \sigma = \frac{8.192 \times 10^7 \times 10 \times 10^{-3}}{4.096 \times 10^{-5}}$$

$$\sigma = 20 \, GPa$$

The solid shaft factor of safety is calculated and given as below.

Factor of safety (n) $= \frac{maximum\ load\ which\ the\ shaft\ can\ sustain}{load\ acting\ on\ the\ shaft\ (W_s)}$

$$= W/W_s$$

Load acting on the shaft consists of roller weight which is approximately 0, 1962 N and weight of the passing plastic of which it's approximately negligible

$$n = \frac{1.6384 \times 10^8}{0,1962}$$

$$n = 8.35 \times 10^8$$

The factor of safety is very high hence the life span of the shaft is increasingly high making the design very safe.

Single row deep groove radial ball bearing is suitable to use. From appendix 6, bearing number 204 is chosen with a 20mm bore, 47mm outside diameter and 14mm width.

### 5.2.3: Design of tap bolts
Selecting bolt of course series with a designation of M2.They are screwed into a tapped hole of the parts to be fastened.

**Stresses in a tap bolt due to static loading**

Tensile stress due to stretching of bolt

Bolts are designed basing on direct tensile stress with a greater factor of safety to justify for the stress indeterminate.

The initial tension in a bolt is given by:

$$P_i = 2840 \times d$$

Where $P_i$ = Initial tension in a bolt

$d$ = nominal diameter of bolt

$$P_i = 2840 \times 2 \times 10^{-3}$$

$$P_i = 5.68 \ Nm$$

### 5.2.4: Selection of Longitudinal heat sealer and the roller cutter

The heat roller sealer has 40 mm diameter hence 125 mm of plastic is sealed per one complete revolution and a sealing Teflon coated wheel of 3 mm. It seals the longitudinal ends of the plastic. Its temperature is adjustable and it ranges from 30 – 220°C. The separation distance between the sealing widths is 194mm. The rollers rotates at 2revolutions per minute. Temperature suitable for sealing the plastic material ranges from 45 to 50°C. The cutter which does the final sealing, seals and divides by cutting and it rotates at $^1/_3$rpm. Hence a packet is sealed every minute and for 7 working hours, 420 packets are sealed.

### 5.2.5: Design for springs on the plastic support



*Figure 9: Spring mechanism*

The type of spring used is a helical spring because it can handle both tensile and compressive loads.

Let D be the spring mean diameter and d be the spring wire diameter and W be spring maximum load, the twisting moment of the spring;

$$T = W \times {^D/_2}$$

According to www.cigrjournal.org/index,php/Ejournal/article/download/1538/1339 the average push strength with a right hand of a person is 68.7N whereas the average pull strength is 54.4 N. Hence the average is 61.55N

$$T = 61.55 \ \times d$$

$$T = 61.55d \quad \text{................................ (1)}$$

Also the twisting moment,

From Appendix 4, $\sigma = 651\ MPa$ and the spring material is carbon steel and the spring is subjected to light service.

$$T = {}^{\pi}/_{16} \times 651 \times d^3$$

$$T = 128d^3 \quad \text{................................. (2)}$$

Equating (1) and (2)

$$d^2 = {}^{61.55}/_{128}$$

$$d = 0.48\ mm$$

Hence from appendix 5, standard wire gauge is 26 with a diameter value of 0.457

**Mean Diameter**, $D = Cd$

$$= 5 \times 0.457$$

$$D = 2.285\ mm$$

**Outer diameter**,

$$D_o = D + d$$

$$D_o = 2.742\ mm$$

**Inner diameter of the coil,**

$$= D - d$$

$$= 1.828\ mm$$

Approximate axial deflection of the spring is 6mm. From appendix 4, $G = 84kN/m^2$

$$6 = {}^{8WC^3n}/_{Gd}$$

**Number of coils** $\qquad n = 10$

**Free length**, $L_f = nd + \delta_{max} + 0.15\delta_{max}$

$$L_f = (10 \times 0.457) + 6 + (0.15 \times 6)$$

$$L_f = 11.47mm$$

**Pitch of the coil** $= \frac{L_f}{n-1}$

$$= 3.55mm$$

The spring material should have high ductility and fatigue strength.

## 6.0: Bill of Quantities
*Table 1: Bill of Quantities*

The prices of the components given have been taken from regional and international suppliers

| Item Number | Description | Quantity | Unit | Material | Unit Rate ($) | Amount ($) |
|---|---|---|---|---|---|---|
| 1 | Heat roller sealer | 1 | № | - | 34.00 | 34.00 |
| 2 | Heat sealer and cutter | 1 | № | - | 40.00 | 40.00 |
| 3 | 1mm Galvanised sheet | 1.46 | $m^2$ | Cast Iron | 35.00 | 51.10 |
| 4 | 20mm diameter shaft | 2.25 | $m$ | Mild steel | 8 | 18.00 |
| 5 | 0.457mm diameter spring | 2 | $mm$ | - | 0.21 | 2.40 |
| 6 | M2 bolts | 72 | № | - | 0.50 | 36.00 |
| 7 | № 204 Radial ball bearing and casing | 4 | № | - | 5.00 | 20.00 |
| 8 | Weight meter | 1 | № | - | 15.00 | 15.00 |
| **Total costs** | | | | | | **216.50** |

The outside casing is made of cast iron because of its tremendous absorption of the energy of vibration. The price of the components of the machine from the objectives is justifiable as depicted by the bill of quantities.

## 7.0: Conclusion and recommendations
The design operates on simple mechanical principles. The cost from the objectives is justifiable as depicted by the bill of quantities. The machine have a capability of packing 1packet which weighs 1kg per every minute. I would recommend the improvement of the machine so that it can pack a range of weights and the plastic should move automatically from the spring plastic holder.

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## Biography

**Tawanda Mushiri** received the B.Sc. (Hons) in Mechanical Engineering and M.Sc. Manufacturing Systems and Operations Management degrees from University of Zimbabwe in 2008 and 2012, respectively. During 2008 – 2010, he went on to do a Graduate Trainee Learner ship from Oil Company under the Ministry of Energy and Power Development in Zimbabwe. He also worked as a Graduate Teaching Assistant at Chinhoyi University of Technology from 2011 to early 2013 teaching machine intelligence and advanced control and robotics. He is now a lecturer at the University of Zimbabwe from March 2013 to date teaching Engineering dynamics and design. He is a PhD student at the University of Johannesburg.

**Charles Mbohwa**'s research activities and interests are in logistics, supply chain management, life cycle assessment and sustainability, operations management, project management and engineering/manufacturing systems management. His current Google Scholar h-index is 6 and Scopus h-index is 5. Currently is the Vice Dean of Research at University of Johannesburg and a full professor.