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Design of a semi automated de-lidding machine for SMEs bakeries

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Abstract: A semi-automated de-lidding machine which removes lids from baking pans was designed. Modeling of the design was done using mechanical design calculations. The results were simulated using AUTODESK for Finite Element Analysis to validate the model. Centered on technology transfer and the national economic recovery blueprint under the value addition and beneficiation cluster, this research aims to automate and hence improve productivity in bakeries using mechanical design calculations and finite element analysis. The machine has a picking and placing unit that uses electromagnetism, coupled with a chain for material handling and a control circuit. The automated system comprises of pneumatic cylinders, electromagnet, banner sensor and conveyor chain. The machine was able to increase the lid removal rate by 26%.

Keywords: De-Lidding, Technology Transfer, Control Circuit, Semi Automated, Finite Element Analysis

1. Introduction

Currently bread is one of the fastest consumable basic commodities in Zimbabwe and makes the cornerstone of each breakfast. The bakery industry is being faced with the challenge to be innovative to design or redesign new machines and methods so that bread is produced at the lowest possible time and cost in order to be competitive. The manual process of removing lids from pans in bakeries is labour intensive, causes damage to some lids and also poses a danger to the people handling hot and heavy lids.

After carrying out work study at bakeries in Harare for more than six months, the researchers noticed that removing lids manually from pans is a bottle neck in the system and also causes damage to some lids as workers throw the lids which result in lids failing to fit the pans. In addition to that, manually removing of lids causes occupational injuries at times as the pans and lids are always hot when they are coming out of the oven.

2. Structure of Design Research

The aim of this research was to design and manufacture a semi-automatic de-lidding machine and the objectives which were set were to:

- Design the picking and placing unit that uses magnetism.
- Design chain for material handling.
- Design the drive unit for the conveyer chain.
- Design the control circuit for the picking and placing unit.

The authors believed the justification for this research the delay in production, could be improved with great benefits for the bakery companies. The de-lidding process had a seriously negative effect on health & safety policy and could affect profit making. In addition, the quality of the bread produced was adversely affected by this phenomenon since thrown lids could not give a tight fit due to deformations caused by throwing. The companies were failing to meet the demand for bread as could be seen by shortages in super markets. The scope of the research was to provide a solution to the de-lidding problem. This research was directed to problems faced by small holder firms and large bakeries. The machine designed was anticipated to be suitable for high, medium and low production volumes.

2.1. Technology Transfer

De-lidding machines are already in existence in some countries. However they are expensive to purchase and the process to get them to the country in question is tedious and time consuming. Furthermore the machines are tailor-made to suit the production scenarios in those countries and would require further training of manpower for maintenance. Thus the researchers have decided to transfer these technologies and design them to suite the exact scenario being faced in the country. Also the design would use only material available in the country such that maintenance is easy and affordable. Also the advantages of these de-lidding machines e.g. low impact, no unnecessary movements, small layout area and room for further adjustments or improvements have been combined into this one machine. The following are machines available mainly in United States of America and United Kingdom and their advantages and disadvantages.

2.2. Techquip De-Lidding Machine

TECHQUIP Company is a British company which specializes in manufacturing of bakery equipment ranging from dough mixers, pocket proofers, rounder, moulder and de-lidding machine. This type of De-lidding machine manufactured by TECHQUIP employs the system of magnetism and conveyer to remove lids from pans. The de-lidding machine is situated on top of the main conveyer which conveys pans from the oven out-feed.

The major drawback of this de-lidding machine is that it is not flexible in its setup as it does not offer alternative route for temporary storage of lids in the case of the lid conveyer jamming up or full of lids[1].

2.3. Gostol Robotic De-Lidding Machine

The machines of this family are designed for de-lidding and de-panning of baked bread. They are suitable for use on the automated industrial lines. They are designed so that they combine operations of two usual machines (de-panner + de-lidder) performed within one cycle. The machine is composed of: 5-axis industrial robot, gripper for de-lidding, multi-segment gripper with vacuum suction cups for bread, vacuum station and computer software [2].

2.4. Capway De-Lidding Machine

In the case of low to medium capacity systems, the Pick 'n Place machine for lidding and de-lidding is used. After the baking process, the lids are removed from the baking forms one by one. They are then placed back on before or after proofing. This is carried out by means of grippers.

In the case of medium to high capacity systems, we prefer the in-line de-lidder and lidder. These machines lift the lids from the forms in the process by means of permanent magnets, and placed back again in the flow. The advantage of this type of machine is that it is low impact: no unnecessary movements and no time loss[3].

2.5. The Bread Making Process

The pans leave the oven at high temperatures of range 200-250□C. The oven out-feed consists of a table frame fitted with rollers which acquire their drive from 0.75 kW electric motors. There are two sets of rollers with one set which moves at constant speed whilst the other set is inter-connected with infra-red light sensors such that the rollers increase speed as soon as the infra-red light sensors detect the presence of pans. Upon detection of pans by infra-red light sensors, there is an on-time delay of 5 seconds which actuates a pressure cylinder and allows a conveyer to carry the pans away from the oven out-feed. As the pans move away from the oven out-feed, two workers remove lids from the pans. The lids are loaded on a conveyer which goes back to the lidding station or loaded on iron-steel trolley. The human workers interchange after every one hour due to the high temperatures situated at the oven out-feed. The workers at times throw the lids on the floor or in the trolley which leads to deformation of the lids thus requiring panel beating before the lid can be used again. Moreover, due to the high temperatures of the lids as they come out of the oven (200-250□C), elimination of human labour at the oven out-feed enables elimination of injuries due to serious burns thus the company will save thousands of dollars in compensating injured employees.

This challenge being experienced by bakeries has led the researchers to embark on the design of a de-lidding machine.

3. Materials & Methods

The researchers designed the picking and placing unit that uses magnetism, selected the chain for material handling and the drive unit for the conveyer chain. Design calculations included shaft design, lid design, chain drive design and material selection. Lastly they designed the control circuit for the picking and placing unit.

Literature review on de-lidding mechanisms was undertaken and used as a basis for introducing summary of examples on how they benefited various bakery industries. Interviews, questionnaires and direct observation provided insight into the lid removal process and areas which could be improved. After data collection in various bakeries an analysis was done to come up with a common solution of what people are thinking about the machines. Pie charts and bar graphs were used as data analysis tools. The analysis shows that 10% of the population said there was no need such machine because they cause others to lose their jobs. 15% declared they needed the machine to be bought from manufacturers abroad. 75% stated that they preferred the machine to be designed and manufactured locally.

The results from this data analysis were a further justification of the need for a new design of the de-liddding machine. This analysis forced the bakery company's management to move a step further and provide resources for designing the machine.

3.1. Results & Development

The development started with material selection, design calculations, detailed drawings and a design analysis was finally done. These processes were repeated for each and every component until the machine was completed. Software like MASTERCAM was used in the drawings.

3.2. Prototyping

In this research a prototype was made and it was used as a method of evaluating the feasibility of the proposed design. After prototyping the machine was run several times in order to ascertain the validity of the design relative to the problem at hand.

3.3. Production Rates

The current removal rate of lids was 875 lids per hour manually. The de-lidding machine improved the capacity to removing 1 100 lids per hour.

4. Results & Discussion

After product analysis, management identified losses in the system and then picked up de-lidding as one of the delaying processes. The workers threw the lids down due to the high temperatures involved. This was costing the company huge sums in overtime payments and failure to meet targets as well as quality costs. Upon completion of this design, it was anticipated that these issues would be addressed with the installation of several of these locally produced de-lidding machines.

After analysis of each design the three solutions were compared against each other in order to find the most suitable one for the problem at hand. A decision table, as shown in Table 1.0, exactly the same as the house of quality was employed for this particular task. The attributes discussed in the design analysis for each solution were used as the basic factors for the selection process.

Table 1. *Concept Selection.*

Attribute	Points	Solution 1	Solution 2	Solution 3
Functional analysis	10	9	9	9
Product safety and reliability	20	15	16	15
Cost	20	14	15	16
Mechanical strength	15	12	12	12
Manufacturability	15	14	13	13
Robustness/ stability	10	6	9	7
Maintainability	10	7	8	6
Total	100	77	80	78

4.1. Selected Solution

After a critical analysis solution two was proved to be the best for the desired application. The design was expected to be manufactured at reasonable cost, as the economic viability was an important consideration in the development of the design. There were no complicated manufacturing methods required for this design. From the functionality point of view the design had all the necessary features to carry out the desired tasks. This design was stable, robust and could be maintained without any difficulties. It was the researchers' chief concern that the machine satifies all food industry board requirements in line with health and safety, hence the design required that all components be made of a food grade material.

4.2. Design Calculations

4.2.1. Selected Materials

The researchers selected stainless steel grade 304L. This is a food grade material which is much cheaper than the other substitute materials due to its chemical composition.

This alloy consists of: Mn = 2%, P = 0.045%, S = 0.03%, Si = 1%, Cr = 18% and Ni = 10%.

Stainless steel 304L is non-corrosive; it has high strength and considerably good surface finish. It can be machined, welded and cast in to any shape. (AK Steel Corporation, 2007).

Table 2 shows the specifications for motor selection which were derived from the load to be carried.

4.2.2. Frame Design

Frame Analysis Report

Modeling of the design was done using mechanical design calculations. The results were simulated using AUTODESK for Finite Element Analysis to validate the model. The results are as follows.

Fig. 1 shows the overall frame of the de-lidding machine. This was designed for stability and strength so as to be able to withstand all the forces it has to support. Fig. 2a and Fig. 2b only show the results of Force 1 on the elements on the frame of the machine. Simulation and analysis was done using different forces Force 1, Force2, Force 3, Force 4 on different elements of the frame and the results are in Table 9. The results show the machine should not topple when external forces are applied to it; instead the machine was designed to slide on the platform if the forces exceed the frictional force. A very large force is required at the highest point of the machine to start giving a toppling effect. This further justifies the researchers' belief in the stability of the machine.

Fig. 3, Fig. 4, and Fig. 5 show the frame displacement due to the force in the x direction. The criticality of the effect of this force is shown by the change in colour in the elements with blue being ok, and red being critical. These directed the authors in areas which needed reinforcement or redesign in the machine.

Fig 1. *Frame of the de-lidding machine.*

Table 2. *Physical.*

Mass [kg]	25.659
Area [mm^2]	26627.471
Volume [mm^3]	16714.548
Center of Gravity [mm]	x=26551.562 y=-62561.302 z=-15114.193

Table 3. *Simulation 1 - General objective and settings.*

Simulation Type	Static Analysis
Last Modification Date	10/21/2013, 2:29 PM

Table 4. *Material(s).*

Name	Steel, Mild	
General	Mass Density [g/cm^3]	7.860
	Yield Strength [MPa]	207.000
	Ultimate Tensile Strength [MPa]	345.000
Stress	Young's Modulus [GPa]	220.000
	Poisson's Ratio [ul]	0.275
Stress Thermal	Expansion Coefficient [ul/c]	0.0000120
	Thermal Conductivity [W/(mK)]	56.000
	Specific Heat [J/(kgK)]	0.460

Table 5. *Cross Section(s).*

	Section Area (A) [mm^2]	133.699
Geometry Properties	Section Width [mm]	20.000
	Section Height [mm]	20.000
	Section Centroid (x) [mm]	10.000
	Section Centroid (y) [mm]	10.000
Mechanical Properties	Moment of Inertia (I_x) [mm^4]	6921.664
	Moment of Inertia (I_y) [mm^4]	6921.664
	Torsional Rigidity Modulus (J) [mm^4]	12100.000
	Section Modulus (W_x) [mm^3]	692.166
	Section Modulus (W_y) [mm^3]	692.166
	Torsional Section Modulus (W_z) [mm^3]	1060.000
	Reduced Shear Area (A_x) [mm^2]	63.149
	Reduced Shear Area (A_y) [mm^2]	63.149

Operating Conditions

Table 6. *Gravity.*

Load Type	Gravity
Magnitude [mm/s^2]	9810.000
Direction	Y-

Table 7. *Force 1.*

Load Type	Force
Magnitude [N]	100.000
Beam Coordinate System	No
Angle of Plane [deg]	270.00
Angle in Plane [deg]	90.00
Fx [N]	0.000
Fy [N]	-100.000
Fz [N]	0.000
Offset [mm]	200.000

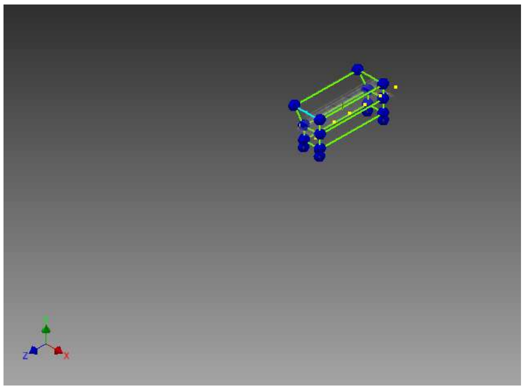

Fig 2a. *Frame force analysis.*

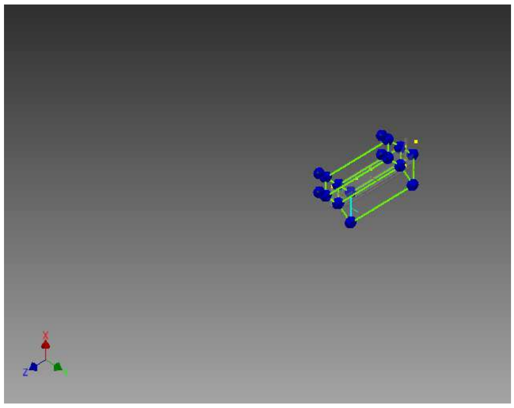

Fig 2b. *Frame Force analysis.*

4.3. Results

Table 8. *Reaction Force and Moment on Constraints.*

Constraint Name	Reaction Force Magnitude [N]	Components (Fx,Fy,Fz) [N]	Reaction Moment Magnitude [Nmm]	Components (Mx,My,Mz) [Nmm]
		-1.873		-178.286
Fixed Constraint:1	148.934	148.803	208.328	-16.028
		-5.960		-106.572
		2.377		201.737
Fixed Constraint:4	96.821	96.568	291.655	-8.296
		6.577		-210.46
		1.822		-218.099
Fixed Constraint:2	101.791	101.552	308.181	15.276
		-6.728		-217.198
		-2.326		220.276
Fixed Constraint:3	153.849	153.710	231.905	22.444
		6.111		-68.953

Table 9. *Static Result Summary.*

Name		Minimum	Maximum
Displacement [mm]		0.000	0.080
	Fx	-569.310	46.550
Forces [N]	Fy	-61.771	530.671
	Fz	-195.517	153.710
	Mx	-5969.842	6182.565
Moments [Nmm]	My	-5928.935	6168.899
	Mz	-117.167	133.437
	Smax	-0.919	9.280
	Smin	-10.029	0.024
	Smax(Mx)	0.000	8.932
Normal Stresses [MPa]	Smin(Mx)	-8.932	-0.000
	Smax(My)	0.001	8.912
	Smin(My)	-8.912	-0.001
	Saxial	-1.150	1.462
Shear Stresses [MPa]	Tx	-0.737	9.015
	Ty	-8.403	0.978
Torsional Stresses [MPa]	T	-0.126	0.111

Displacement

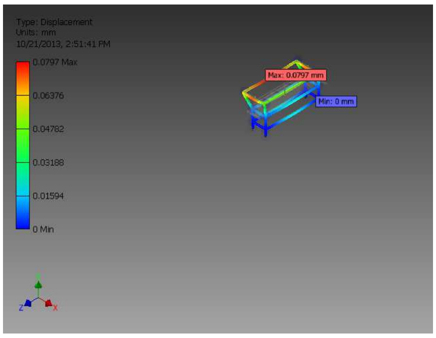

Fig 3. *Frame displacement with F_X.*

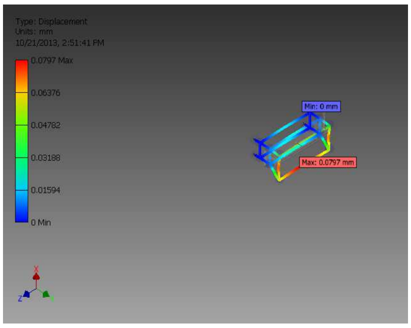

Fig 4. *Critical displacement zones.*

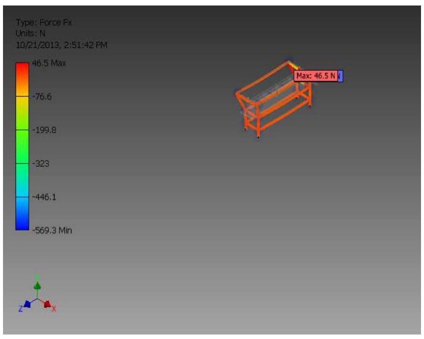

Fig 5. *Critical displacement zone.*

5. Conclusion

The outcome was a highly efficient and reliable machine for medium scale and large scale bakeries that removed lids from pans of bread by using the concept of magnetism and conveyor chain.

The major objectives of this project was to design a picking and placing unit that used magnetism, designing of chain for material handling and designing of a control circuit for the picking and placing unit.

When the machine was tested it exhibited good functionality, robustness, reliability, durability and safety features. The results were in line with the set objectives. The machine is capable of delivering the intended functions in the desired manner. The machine was safe to operate, there were no vibrations and the control system was working as designed. The machine was user friendly and esthetically pleasing. The system had good control resolution, accuracy and repeatability. All stake holders and other interested parties were satisfied by the results of the machine

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