



Conceptual Design of Reverse Vending Machine (RVM): Finite Element Analysis

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Abstract: A reverse vending machine is a machine that uses the concept of giving rewards to those who recycle, but the price of this machine is expensive. The main objective for this research is to design a conceptual design of low-cost reverse vending machine and determined the stress, displacement and also analyse factor of safety for the component of reverse vending machine. This scope of study is this machine is only limited in receiving PET bottle, conducted in solid works software and perform static analysis. Engineering design process which is conceptual design, embodiment design and detail drawing has been used to identify the suitable design. From the data, all the component that been chosen to conduct static analysis can be used in this machine. Not all the component in reverse vending machine is selected to perform analysis, therefore suggestion for future work is to perform analysis to other component as well with other analysis to build a real low-cost reverse vending machine.

Keywords: Conceptual Design, Reverse Vending Machine, Design Process, Low-Cost.

1. Introduction

Due to population increase, the amount of municipal solid waste is increased [5]. Municipal solid waste must be properly managed to limit trash production and environmental effect. One strategy to manage solid waste is to implement recycling. Not all waste can be recycled, thus knowledge and practice are needed in recycling. Lack of knowledge is one of the reasons why people do not recycle [6]. Several practices are used in some countries like Denmark, Norway, Canada, and Japan to tackle the recycling issue. One of them is by using a Reverse vending machine or RVM.

A reverse Vending machine (RVM) is a machine that accepts empty plastic bottles to recycle and gives a reward to the recycler. This machine generally operates by recognising the type of material, separating, process and giving a reward. According to [4] RVM is a good practise to educate the value of recycling behaviour and one method to increase general public involvement in recycling [1] due to incentives like a reward given by this machine. The presence of this machine might help to educate and increase the rate of recycling in Malaysia.

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The aim of this study is to identify the low-cost component for reverse vending machines (RVM). There are several objectives that must be achieved at the end of this research, which are determined stress and displacement analysis and analyse factor of safety at this machine component. The scope for this study is this machine is designed limited in receiving PET bottle, Solidworks software is used in performed static analysis. This study is focused on the conceptual design of RVM using low cost component where cost is the important factor that contribute to the provider not use this machine.

2. Materials and Methods

Figure 1 shows the engineering design process, which has three phases. Phase 1 is conceptual design, where the aim is the evaluation of a concept. For phase 2, which is embodiment design, the aim of this phase is to determine parametric design and lastly, for phase 3, which is detail drawing, the aim of this phase is to have a drawing that can be analysed.

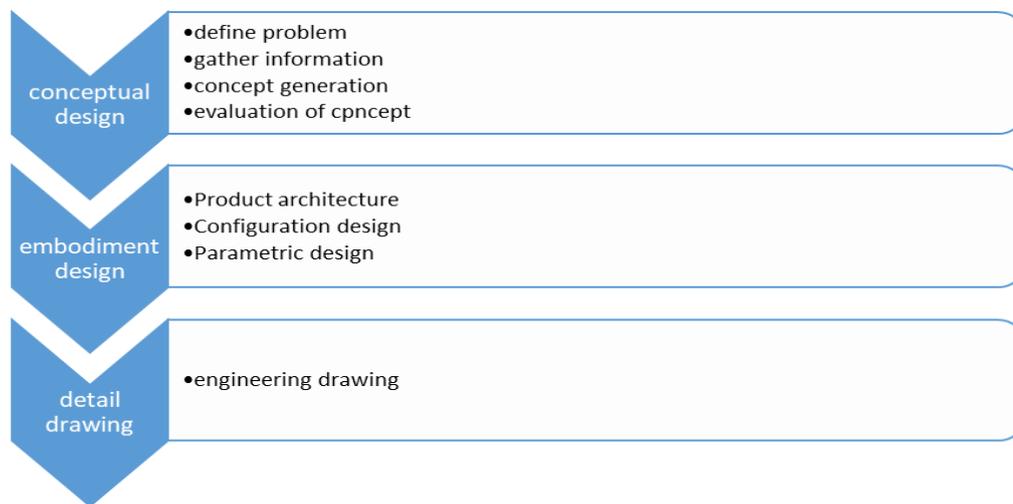


Figure 1: Engineering design process phase [3]

The task for conceptual design is to understand the actual problem, gain information, and build and evaluate a low-cost reverse vending machine. Understanding actual problem has been made as state in introduction. Engineering characteristic has been identified which is the price as the main characteristic. The function of this machine also has been determined from the input, process and output. This function has been detail as shown in Figure 2. In building concept, brainstorming has been made in order build morphological chart. The function of morphological chart is that each component is solved correctly when the main assembly is solved by any combination of potential answers. Three concepts have been sketched and evaluated as shown in Table 1. The evaluation is evaluated by score system, which is the highest the score the better the concept according to design criterion. In addition, the weight factor from the engineering characteristic is used to calculate the rating The best concept, which is concept 1, has been selected because it has obtained the highest score of 2.758 compared to concept 2 with a score of 2.484 and concept 3 with a score of 2.235. There are three tasks in performing embodiment design, which are product architecture, configuration design, and parametric design. In product architecture, the function structure of the reverse vending machine has been created and clustered into 6 modules as shown in Figure 3.

Table 1: Evaluation matrix

Design criterion	Weight factor	Concept analysis					
		Concept 1		Concept 2		Concept 3	
		Score	Weighted rating	score	Weighted rating	score	Weighted rating
Features							
Reliability	0.063	3	0.189	3	0.189	3	0.189
Good Sensor	0.066	3	0.198	3	0.198	3	0.198
Efficiency	0.064	3	0.192	3	0.192	3	0.192
Safe To Use	0.065	3	0.195	3	0.195	3	0.195
Ergonomic							
Environmentally Friendly	0.127	3	0.254	2	0.381	2	0.254
User Friendly	0.13	3	0.39	3	0.39	3	0.39
Cost							
Low Operational Cost	0.082	2	0.164	3	0.246	2	0.164
Low Maintenance Cost	0.084	2	0.168	3	0.252	2	0.168
Affordable	0.083	3	0.249	3	0.249	2	0.166
Design							
Capacity	0.083	3	0.249	2	0.166	2	0.166
Lightweight	0.077	3	0.231	1	0.077	1	0.077
Portability	0.076	2	0.152	1	0.076	1	0.076
Total	1	2.758		2.484		2.235	

Table 2: Analysis on mechanical component

Mechanical component	Analysis type	Value to determined
Electric motor	Force analysis	<ul style="list-style-type: none"> Torque Output, RPM, Power Rating, Efficiency.
Gear	Force analysis	<ul style="list-style-type: none"> Gear Specifications:
Shaft	Force analysis	<ul style="list-style-type: none"> Shaft Diameter and length
Bearing	Force analysis	<ul style="list-style-type: none"> bearing selection, load rating.
Conveyor	Force analysis	<ul style="list-style-type: none"> Size of conveyor, Torque Output, RPM, Power Rating

The next task is performing configuration design, for which the purpose is to determine whether critical assessments of the identifying nature of the analysis on the individual components have been

made. As a result, each component must know the type of analysis and value that they need to determine, as shown in Figure 4.

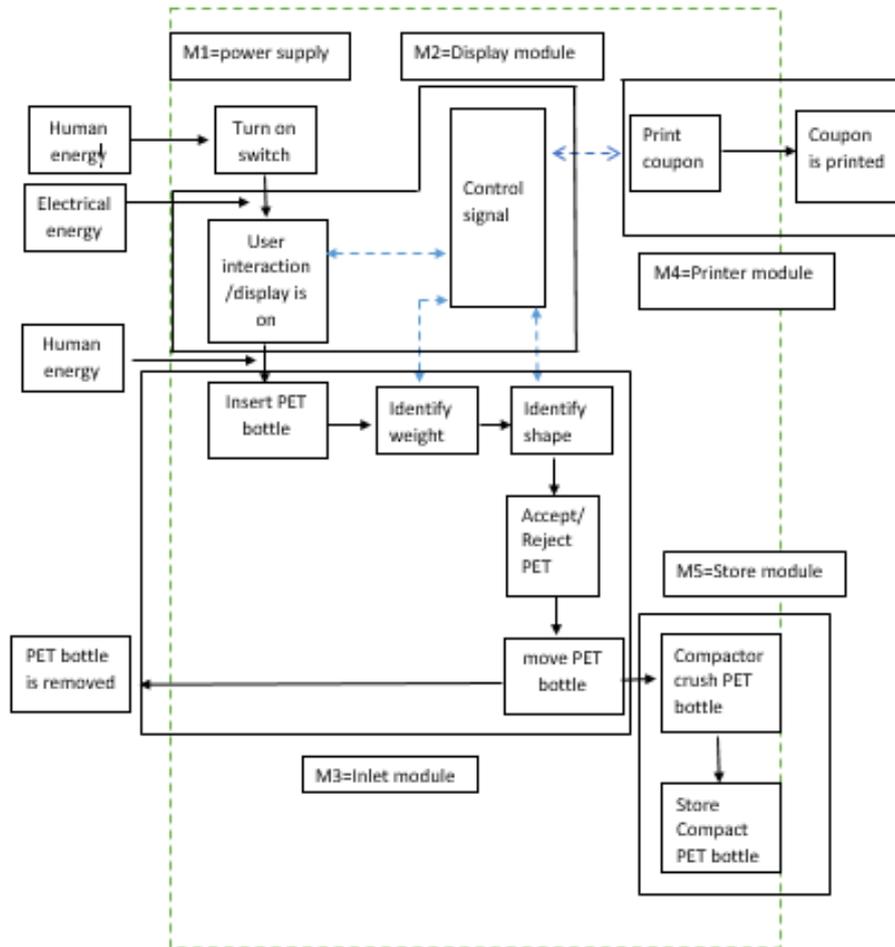


Figure 2: Clustering of schematic diagram of RVM

Parametric design is used to break down the flow of designing reverse vending machines into smaller portions in order to get detailed information regarding the size and dimension of a component. There are two components that have undergone force analysis, such as the compactor and the conveyor. In compactor design, the value of fundamental gear, the minimum diameter of the shaft blade, and the value of bearing load rating have been determined. For conveyors, the minimum dimension of the conveyor and the minimum power needed have been determined. Suitable frame material has also been determined by using the chart [2]. The drawing detail has been made from information gained from parametric design. There are only five detailed drawings made in order to perform static analysis. Both the drawing and the analysis are conducted using Solidworks software. The detailed drawing can be seen in Figure 5.

3. Results and Discussion

In this machine design, the material of the component is based on ductile behavior, which is ($\epsilon_f > 0.05$). Therefore, the theories that have been chosen for this static analysis are the Maximum Von Misses Theory and the Distortion Energy Theory.

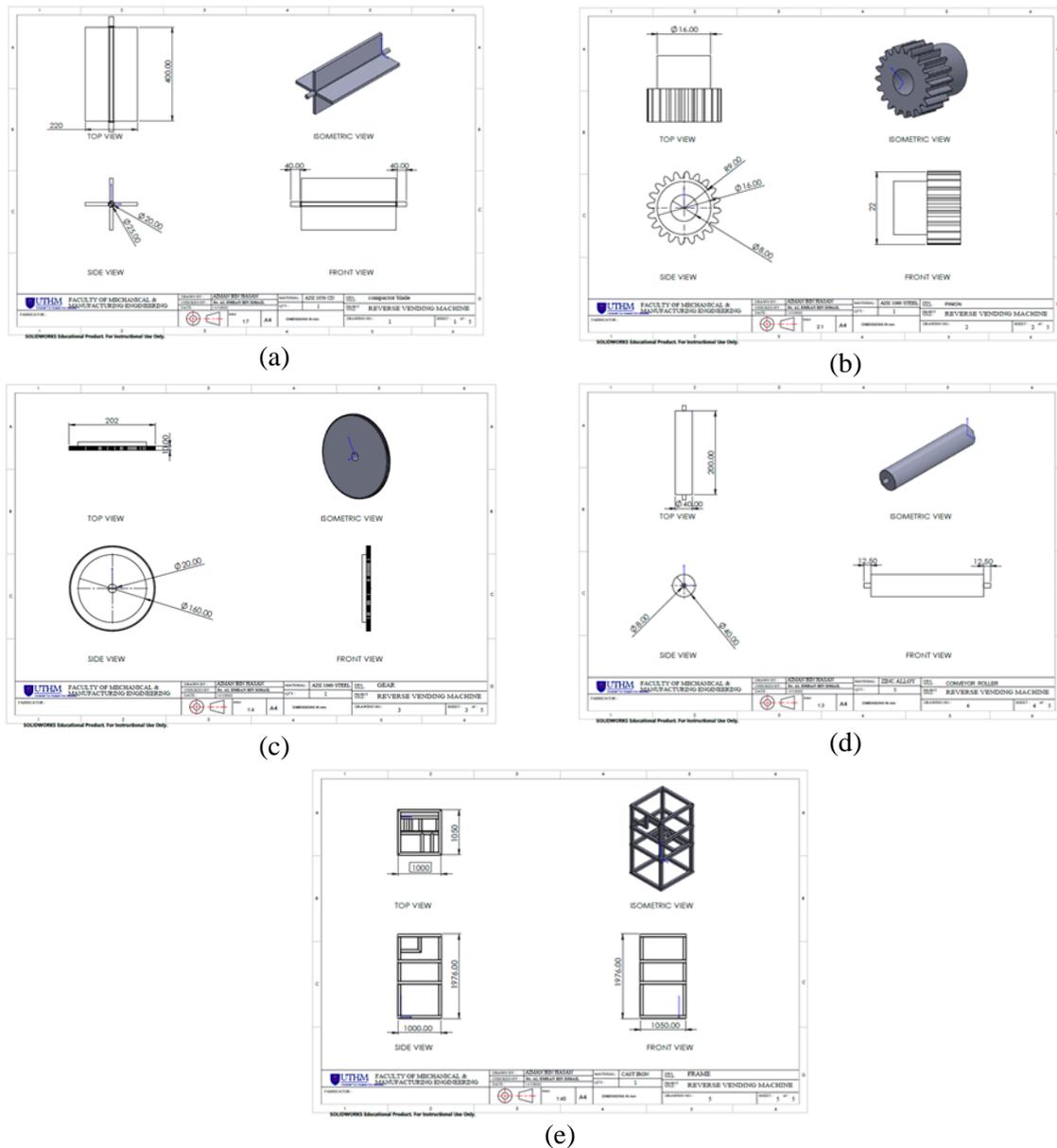


Figure 3: Detail drawing of (a) Compactor blade (b) Pinion (c) Gear (d) Conveyor roller and (e) Frame

3.1 Component 1 Compactor blade

The purpose of the shaft blade is to compact the PET bottle in order to save storage space. The value of maximum stress is held at the shaft of the blade for $2.209 \times 10^7 N/m^2$. This value is less than the yield stress of the material $5.8 \times 10^8 N/m^2$. The highest value of displacement is held at the bottom of the blade, and the lowest value is at the end of the blade. This is caused by the length of the blade from the shaft. Lastly, the minimum value factor of safety 2.626×10^1 has been exceeded 1, so this component can be used in this machine.

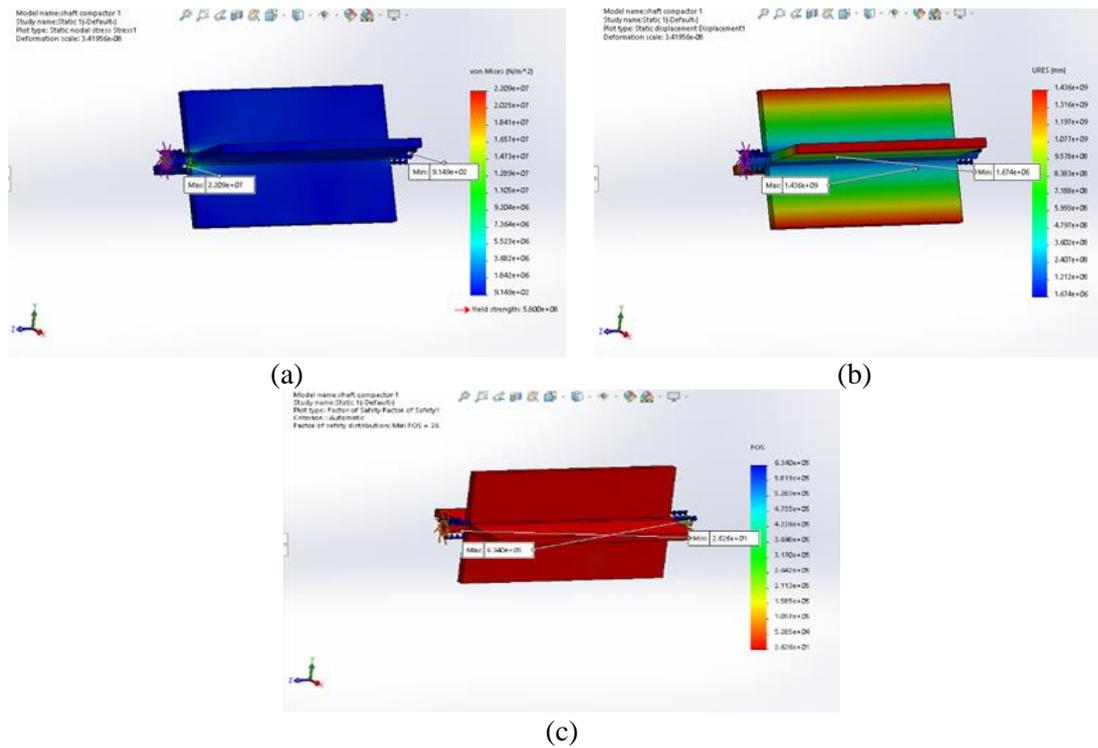


Figure 4: Static analysis of shaft blade (a) Stress analysis (b) Displacement analysis (c) Factor of safety analysis.

Table 3: Value min and maximum of shaft blade in static analysis

Value	Stress(N/m^2)	Displacement(mm)	Factor of safety
Minimum	9.149×10^2	1.674×10^6	2.626×10^1
Maximum	2.209×10^7	1.436×10^9	6.340×10^5

3.2 Component 2 pinion and gear

The function of the pinion and the gear for this machine is to transmit motor power to the compactor shaft to rotate the blade. The value of stress maximum is placed on the face of the pinion at $3.349 \times 10^6 N/m^2$, and the minimum is placed on the back surface of the pinion. The pinion is on 1.81N of torque that came from the torque of the motor. The value of maximum displacement is placed at the edge of the pinion teeth at $4.388 \times 10^7 mm$ and the minimum value is placed at the edge of the pinion hole at $6.66 \times 10^6 mm$. Last but not least, the minimum value of the safety factor is 1.448×10^2 greater than 1, which means this gear is not failing, thus it can be used in this machine.

Table 4: Value min and maximum of pinion in static analysis

Value	Stress(N/m^2)	Displacement(mm)	Factor of safety
Minimum	2.201×10^3	6.66×10^6	1.448×10^2
Maximum	3.349×10^6	4.388×10^7	2.204×10^5

The maximum stress value is held at the gear hole at $2.557 \times 10^6 N/m^2$, and the minimum is held at the gear teeth. The torque of the gear applied is 18.1N, which is transmitted from the pinion. Next, the maximum displacement is at the teeth of the gear for $8.812 \times 10^{-4} mm$ and the minimum is at the

face of the front gear for $1 \times 10^{-30} \text{ mm}$. Lastly, for the value of safety, the minimum is 1.897×10^2 greater than 1, which means this component is safe to use on this machine.

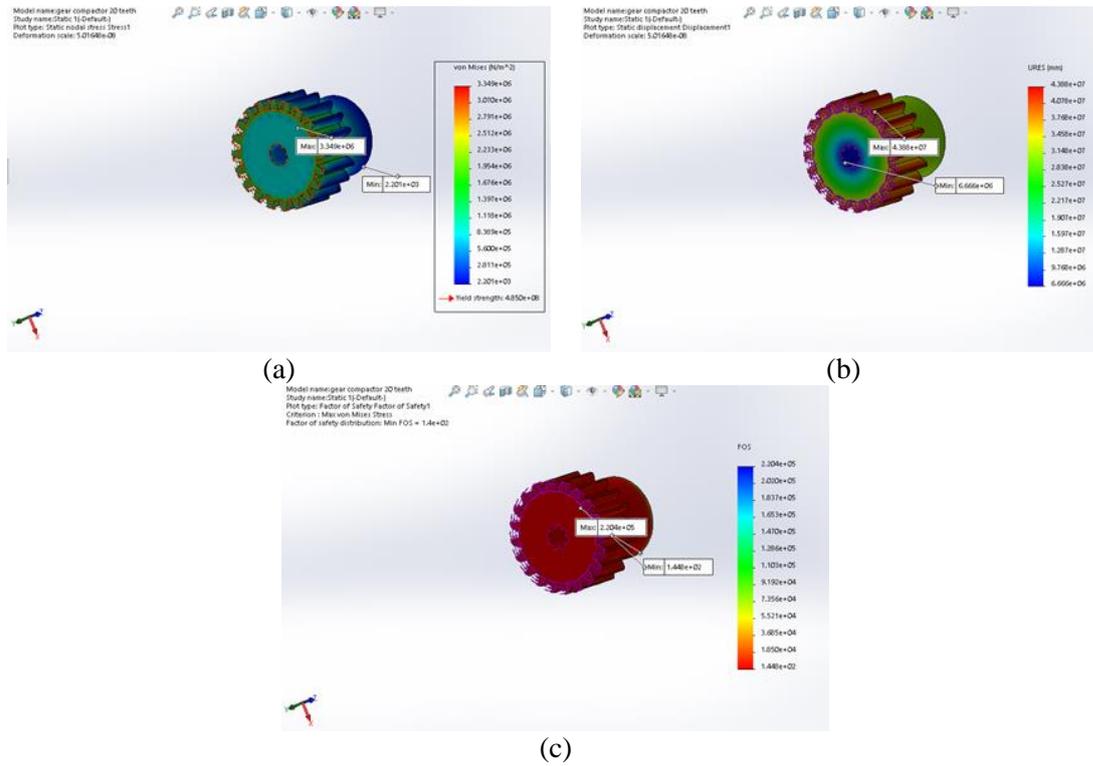


Figure 5: Static analysis of pinion (a) Stress analysis (b) Displacement analysis (c) Factor of safety analysis.

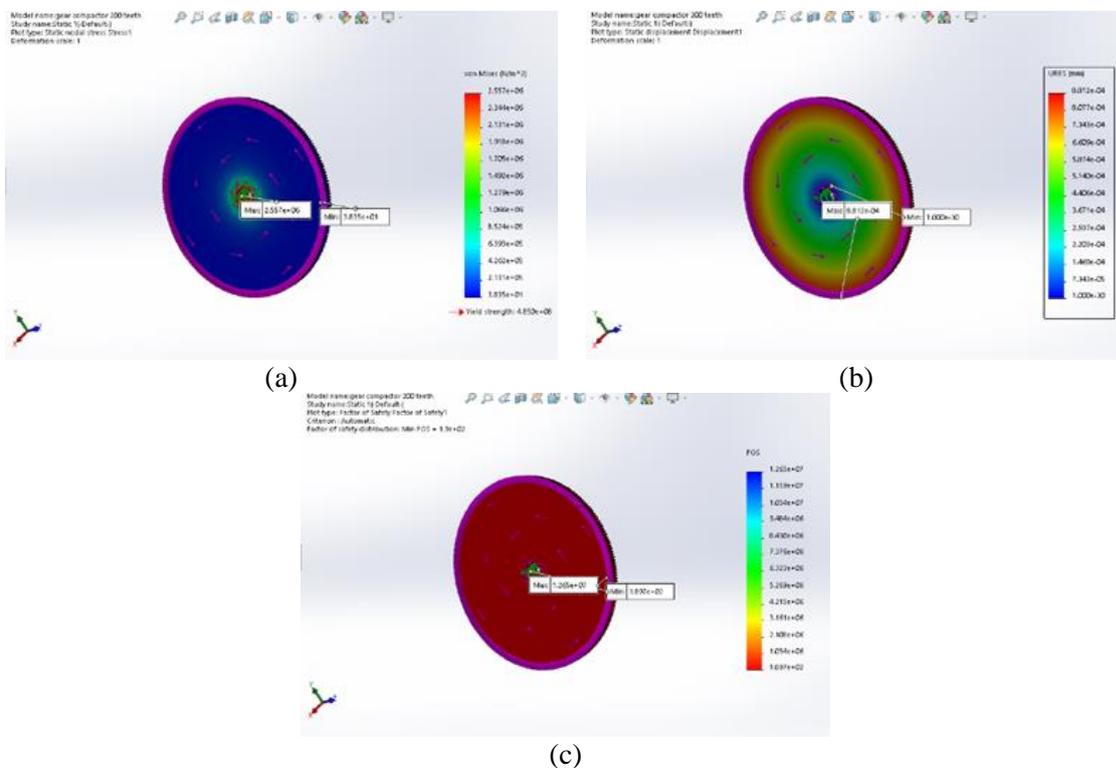


Figure 6: Static analysis of gear (a) Stress analysis (b) Displacement analysis (c) Factor of safety analysis.

Table 5: Value min and maximum of gear in static analysis

Value	Stress(N/m^2)	Displacement(mm)	Factor of safety
Minimum	3.835×10^1	1×10^{-30}	1.897×10^2
Maximum	2.557×10^6	8.812×10^{-4}	1.265×10^7

3.3 Component 3 conveyor roller

The value of maximum stress is $2.411 \times 10^6 N/m^2$, which is below the material's yield strength of $3.72 \times 10^8 N/m^2$. The maximum displacement is held at the roller, which is $5.727 \times 10^7 mm$. The minimum is at the roller shaft at $1.866 \times 10^4 mm$. Therefore, this component can be used in this machine at a minimum safety factor of 1.543×10^2 , which exceeds the value of 1.

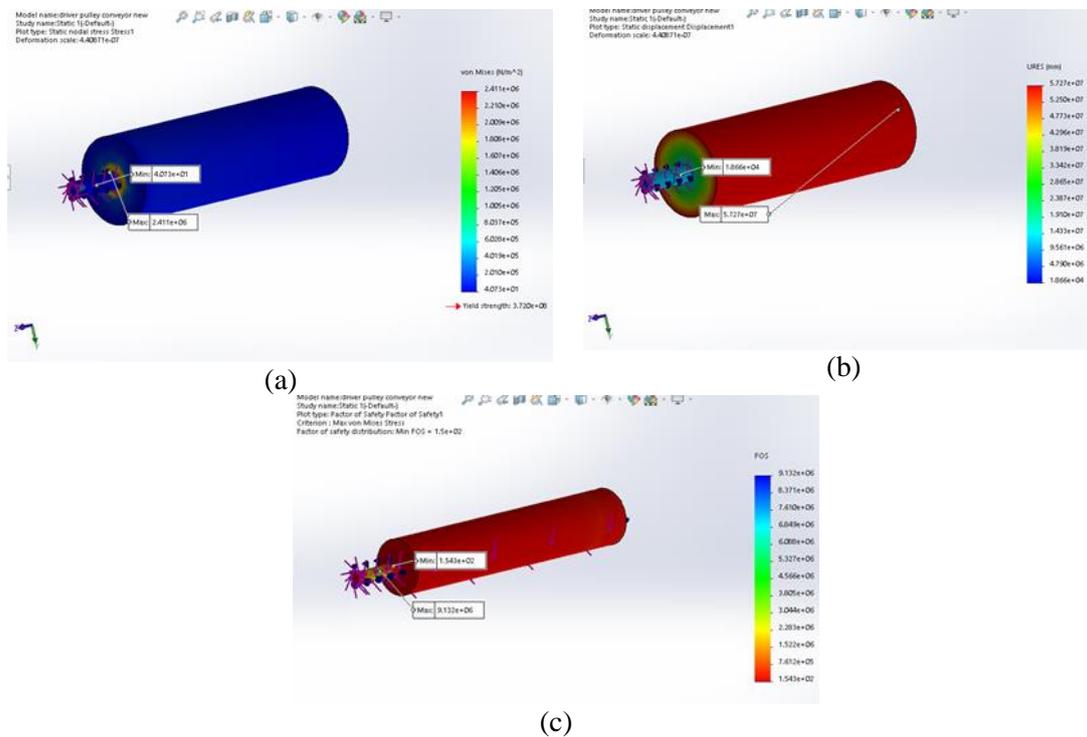


Figure 7: Static analysis of conveyor roller (a) Stress analysis (b) Displacement analysis (c) Factor of safety analysis.

Table 6: Value min and maximum of conveyor roller in static analysis

Value	Stress(N/m^2)	Displacement (mm)	Factor Of Safety
Minimum	4.073×10^1	1.866×10^4	1.543×10^2
Maximum	2.411×10^6	5.727×10^7	9.132×10^6

3.3 Component 4 frame

The function of the frame is to be able to hold the load of a component. The value of the stress on the frame is $7.431 \times 10^5 N/m^2$ for maximum. This maximum value is placed under the load of 100N and the minimum value is placed at a fixed geometry position as shown in Figure 4.6. For displacement,

the maximum value is 0.0207mm. The maximum value for displacement is at the highest position of the combined load, which is 300N, and the minimum displacement is placed at the fixed geometry. The minimum value is 3.711×10^{-2} at the beam of 150 N load, The minimum value for FOS is greater than 1. Therefore, this frame is safe from failure or yielding.

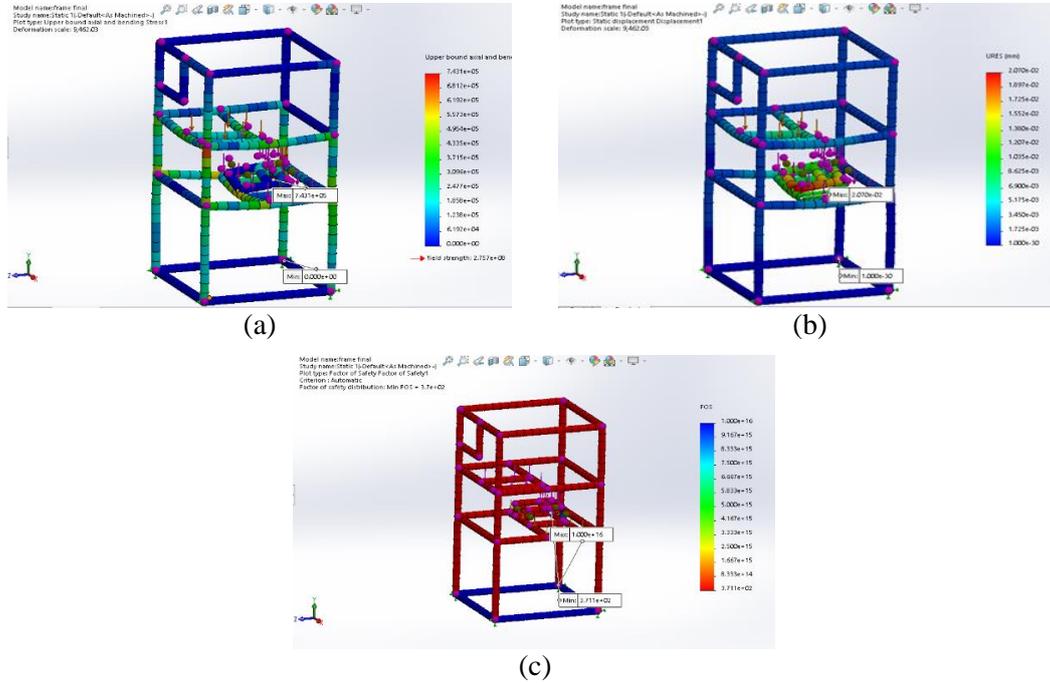


Figure 8: Static analysis of frame (a) Stress analysis (b) Displacement analysis (c) Factor of safety analysis.

Table 7: Value min and maximum of conveyor roller in static analysis

Value	Stress(N/m ²)	Displacement(mm)	Factor of safety
Minimum	0	1×10^{-30}	3.711×10^2
Maximum	7.431×10^5	0.0207	1×10^{16}

4. Conclusion

There’s several conclusion and recommendation for this study on design a concept of low-cost reverse machine. First, the value of factor of safety is exceed the value of failure which is one therefore all the components can be use. Next, this machine component of this research needs to be analysed with more types of analysis than static analysis. Furthermore, not all components have been analysed. Therefore, the recommendation for the next study is to analyse all other components. Lastly, Lack of knowledge of other components such as electrical and Internet of things, so other fields such as electrical must be studied in order to build a true reverse vending machine.

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References

- [1] Amantayeva, A., Alkuatova, A., Kanafin, I., Tokbolat, S., & Shehab, E. (2021). A systems engineering study of integration reverse vending machines into the waste management system of Kazakhstan. *Journal of Material Cycles and Waste Management*, 23(3), 872–884. <https://doi.org/10.1007/s10163-020-01161-9>
- [2] Ashby (2010). (n.d.). *Materials Selection in Mechanical Design 3rd Edition* - By (Michael F. Ashby). https://www.academia.edu/30576917/Materials_Selection_in_Mechanical_Design_3rd_Edition_-_By_Michael_F._Ashby_
- [3] Dieter, & Schmidt, (2009) *Engineering design* (pp. 18-20). Boston: McGraw-Hill Higher Education. (2017). *Engineering design*. In *SpringerBriefs in Applied Sciences and Technology* (Issue 9783319392189). https://doi.org/10.1007/978-3-319-39219-6_7
- [4] Fu-lun, T., Material, I., & Management, F. (2011). *The Study of Beverage Container Recycling Process and Potential Market for Reverse Vending Machine (RVM) in JAPAN*.
- [5] Moh, Y. C., & Abd Manaf, L. (2014). Overview of household solid waste recycling policy status and challenges in Malaysia. In *Resources, Conservation and Recycling* (Vol. 82, pp. 50–61). <https://doi.org/10.1016/j.resconrec.2013.11.004>
- [6] Strydom, W. F. (2018). Barriers to household waste recycling: Empirical evidence from South Africa. *Recycling*, 3(3). <https://doi.org/10.3390/recycling3030041>