

# Machine for the Pineapple Peeling Process

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**Abstract** – In most small / medium scale fruit processing companies in Sri Lanka, the process of pineapple peeling is carried out manually. These existing manual pineapple processing scenarios create issues of inefficiency and high labour requirement. The major objective was to design a suitable pineapple peeling machine, by reducing the time taken to peel one pineapple and to increase the quantity of the production by minimizing the meat wastage and to reduce the labour requirement. The conventional process of the company, which the experiment was conducted for, takes 60 seconds to peel one pineapple and requires one employee. The machine takes 20 seconds to peel a pineapple by one operator. Thus, the machine enables a single operator to peel the total capacity of pineapples for a day (3333 pineapples) in less than 1.85 hours approximately. Hence, implementation of the machine will reduce the number of labourers required. Also, the quantity of the pineapple pulp production will increase due to the minimization of pineapple meat wastage during the peeling process. Saved meat wastage was found by the volume difference of peeled pineapples by labourers and the machine. From 10 pineapples, 1634 cm<sup>3</sup> amount of meat was saved using the machine. Utilization of the proposed machine will significantly enhance the current processing procedure, allowing the company to reach its expected market competitiveness in the pineapple processing industry.

**Keywords:** Efficiency, machine, peeling, peeler, pineapple

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## Nomenclature

FG - Food Grade

$F_b$  - Force acting on the blade

$\alpha$  - Cutting angle

## 1 INTRODUCTION

Pineapple *Ananas comosus* (L.) is a tropical fruit widely used for producing processed foods such as soft drinks, concentrated juices and jam in Sri Lanka (Baruwa, 2013) (Hossain et al. 2015). Generally, fruits are highly perishable commodities and processing is essential to enhance their longevity (Joy, 2010). In the case of seasonal products, consumers are willing to pay for processed products than the raw products. Therefore, food processing is currently a demanding industry (Moniruzzaman et al. 1988). Unlike some other fruits, pineapples have to be pre-processed quite extensively to make it suitable for further processing (Sulaiman et al. 2000; Lirneasia, 2011). Peeling is one main pre-processing steps carried out manually at most processing plants Sri Lanka. Manual processing demands high labour involvement and meat wastage and make the entire

process lengthier and inefficient. Manual process cannot ensure uniformity and quality of the final product. In order to address this problem, the producers are of the view that the peeling process needs to be mechanized appropriately. Therefore, the objective of the study was to design a suitable machine that would ensure efficiency, quality and uniformity of the pineapple peeling process. Figure 1 represents the processing steps of the machine proposed.

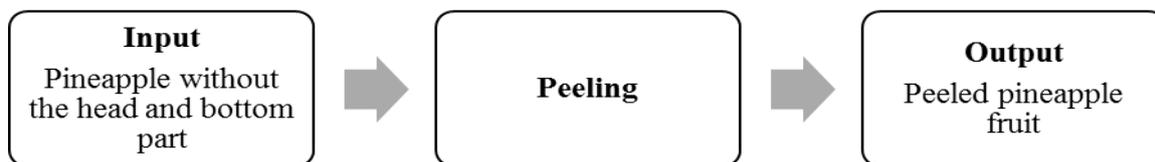


Figure 1: Processing steps of pineapple peeling machine

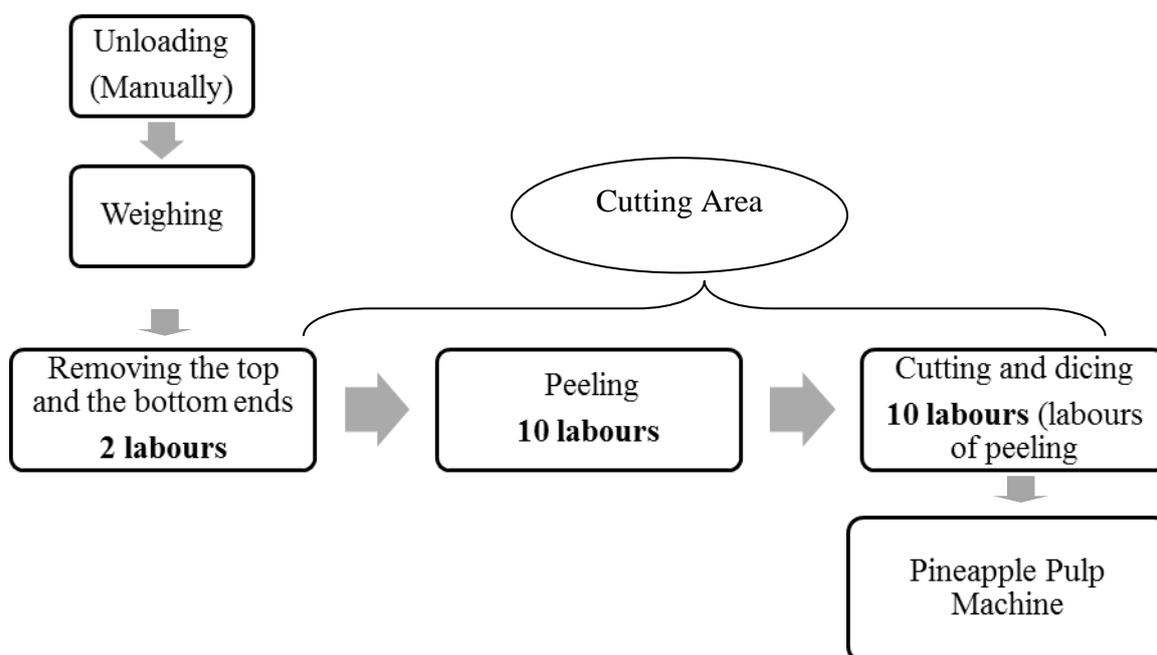


Figure 2: The existing processing steps

The existing pineapple processing steps of the company is represented by the Figure 2. When considering the time, the time taken to enter a pineapple to the cutting area is greater than the time taken for the complete process at the cutting area. For example; the total time taken for the process at the cutting area is 10 minutes and the time taken for a pineapple to enter the cutting area is 45 minutes. If the proposed machine is introduced, it will reduce 10 minutes at the cutting area to 3 minutes. However, when considering the 45 minutes taken for previous steps, the reduced time will not greatly affect the complete processing process. Since there are limitations and restrictions to increase the efficiency of the steps prior to the cutting area, the efficiency enhancement has been concentrated to the cutting area by introducing the designed machine.

The existing manual pineapple processing steps of the concerned company creates issues of inefficiency and high labour requirement. Therefore, the company lacks the possibility of achieving the production targets and increasing the rate of production in a shorter period of time. Thus, it is most desirable to introduce a pineapple processing machine to increase the production of the existing procedure. The analysis of the problem was

conducted through practical measurements and by evaluation of questionnaires. By carrying out a practical using the Archimedes principle, the volume of 10 pineapples were measured before peeling and after peeling as initial volume and final volume. The average time to peel one pineapple fruit was measured and recorded as 60 seconds. The average number of pineapples peel per day by the current process is about 3333. Time taken to peel a pineapple by one labourer is 60 seconds. Ten labourer at the cutting area peels 10 pineapples by 60 seconds. Approximately, a labourer peels 3333 pineapples in 5.55 hours. The proposed machine should be able to achieve the above-mentioned target in a shorter period of time in order to increase the efficiency of the peeling process.

Moreover, considering the production of waste, reducing the meat wastage is a significant factor to increase the output. Suitable techniques were incorporated in the design to minimize the waste generation. The company mainly desires to reduce the labour requirement for the process by replacing the manual peeling process to a mechanized process.

To address the issue, this study was focused on designing and developing a peeling machine to enhance the quantity and quality of products by increasing the efficiency of the pineapple processing process.

## 1.1 Aim

To increase the efficiency of the pineapple processing process, by introducing a pineapple peeling machine.

## 1.2 Objectives

- To design and develop a suitable pineapple peeling machine;
- To save time by reducing the time taken to peel one pineapple fruit of the existing pineapple processing setup
- To increase the quantity of the production by minimizing the meat wastage
- To reduce the labour requirement

## 2 DESIGN OF THE MACHINE

The machine is manually operated and accommodates one pineapple fruit without head and bottom part at a time. The pineapples available at the market are in a wide range of sizes. Therefore, size of the pineapples to be peel by the machine was decided and it can be considered as a design constraint.

In this machine, the threaded bar and the pineapple fruit is rotated by using the annulus (ring wheel) and the planetary internal gear meshing system. In that point, the pineapple fruit will be rotated in a speed of  $10\pi\text{rads}^{-1}$  by a one planetary gear. While the threaded bar is rotated by the other planetary gear, a linear motion has been obtained for the cutting arm by the rack and pinion system. Since the cutting arm is spring tensioned, the pineapple fruit will be peeled out in a curve shape while moving in a linear motion. Thus, the thickness of the peeled-out pineapple peelings remains unchanged. For the reason, the peeling out space in the cutting blade is constant. Practically, the thickness of the peelings is in the range of 8 mm-10 mm. And, by that, the pineapple fruit will not turn unnecessarily. Therefore, the meat wastage can be reduced.

For ease of operation and to ensure the quality of products the following aspects were critically considered.

## 2.1 Ergonomics

Ergonomics is the relationship between people, machine and work environment. In order to prevent injuries from crushing, cutting and thermal exposure, machine ergonomics standards are critical (Iqbal et al., 2011). Designing, examining, testing and evaluating the design and how operators interact in it created productive and safe work environment using the ergonomics principles.

- Machine requires less space and easy to handle, dimensions of the machine are 300mm width, 400 mm length and 220 mm height. The stand is 900 mm. The weight of the machine is 10 kg and the stand is 6.5 kg. Thus, the total weight is 16.5 kg.
- The machine and the mechanisms were designed considering more on simplicity. Thus, the Control movements are simple and easy to perform.
- In this pineapple peeling machine; when the arm moves towards right end, no need to move the arm to its initial position by rotating thus pulling is enough.

## 2.2 Limitations

There is an exact size range of pineapples such as Length (120 - 240) mm and the Diameter (70 - 140) mm can be peeled by the machine. Pineapples must not be over ripened. Over ripened pineapples cannot be peeled by the machine.

## 2.3 Materials

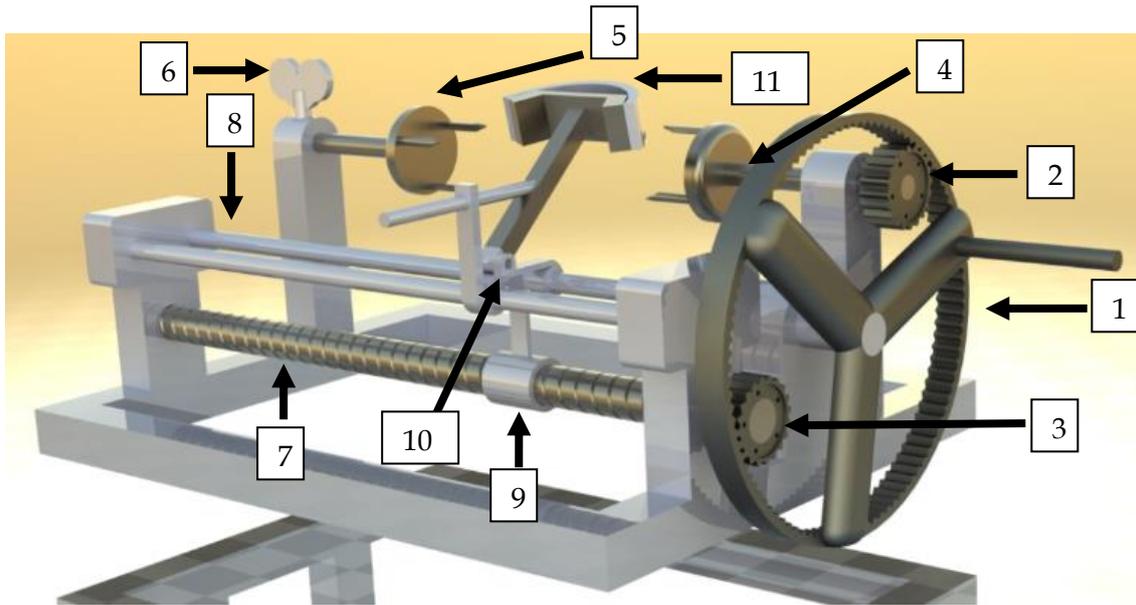
Materials used for the construction of the pineapple peeling machine must fulfil certain specific hygienic requirements. Stainless steel is used for the blade material which is resistant against corrosion. Contact surfaces are smooth enough to be easily cleanable. Food compatible lubricants and greases / coatings should be used for lubricating contact surfaces. The machine should be designed such a way that lubricants do not come into contact with the fruit (Festo, 2017; Lawate, 2007).

The food compatible lubricants used for the design are shown in **Table 1** (Lanka IOC, 2017).

**Table 1: Lubricants**

Product Lanka IOC	Kin. Viscosity cSt at 40°C	VI Min.	Flash Point, °C Min.
Servo system FG 32	29 - 35	135	210
Servo system FG 46	42 - 50	130	220
Servo system FG 68	62 - 74	130	220

## 2.4 Parts of the prototype machine



**Figure 3: Parts of the prototype machine**

Parts of the manual pineapple peeling machine design displayed in Figure 3.

1. Ring wheel with the handle
2. Planet wheel which is connected to three jaw holding shaft
3. Planet wheel which is connected to thread screw bar
4. Rotating 3-jaw shaft which hold the fruit
5. Three jaw fruit holding shaft from the other side (supporter)
6. A lock which helps to hold the supporting 3 jaw shaft
7. Screw shaft which helps to give a linear motion to the arm
8. The two-sliding shaft which helps to move the arm on it
9. Interior threaded hollow shaft
10. Spring tensioned arm which helps to get blade force on fruit
11. Cutting blade

## 2.5 Operational mechanism of the designed machine

The operational mechanism is described along with the parts of the machine given in Figure 3.

- Firstly, the ring wheel (1) should be rotated by holding the handle.
- Then, the planet wheel (2) will rotate. Consequently, the planet wheel (3) and the rotating 3-jaw shaft (4) rotates.
- At this point, the pineapple fruit held between rotating 3-jaw shaft (4) and the 3-jaw fruit holding shaft (5) will rotate.
- Spring tensioned arm (10) and thread bar can be connected by threaded hollow bush (10). At that point, the arm body will move towards the gears.

- The peeling process start and continues as shown in Figure 4.



Figure 4: Peeling process

- After peeling, the arm body can be moved left side through the shaft by rotation of ring wheel (1) opposite side.

### 3 DESIGN CALCULATIONS

#### 3.1 Maximum blade force

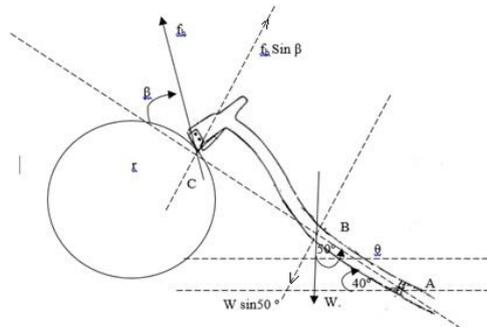


Figure 5: Blade forces

Figure 5 illustrates the forces acting on the blade.

Size of the fruit:

Average length of a pineapple fruit =  $220 \times 10^{-3} \text{m}$

Average radius of a pineapple fruit =  $65 \times 10^{-3} \text{m}$

Blade details:

Blade material = Stainless steel

Blade length =  $60 \times 10^{-3} \text{m}$

The values of cutting angle ( $\alpha$ ) and cutting force ( $F_b$ ) given in Table 2 were obtained by an experimental trial.

$F_b$  = Force acting on the blade

$\alpha$  = Cutting angle

$r$  = radius of pineapple fruit

$W$  = Weight applied

**Table 2: Practical readings on different types of pineapple fruits in different points**

Type of pineapple fruit	Weight applied on Newton scale (N)		
	Left side of the pineapple fruit	Middle of the pineapple fruit	Right side of the pineapple fruit
Raw	33	37	29
Ripe	48	54	51
Half Ripe	39	43	30

Therefore, force acting on the blade  $(F_b) = 40N$

### 3.2 Screw shaft calculations

Mean radius of the shaft was assumed as  $(r) = 16 \times 10^{-3}m$

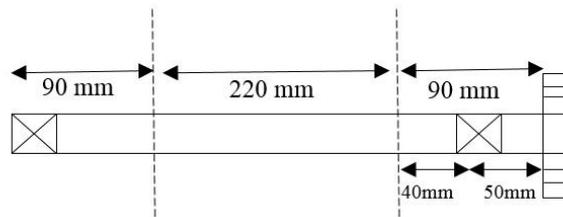
Tooth angle  $(\alpha) = 20^\circ$

Reaction force on the screw shaft  $(F_R) = 3.48N$

Total torque of the screw shaft  $(\tau_z) = 0.02N$

Friction force acting on the screw shaft  $(F_f) = 2.44N$

Therefore, Normal load acting on the gear  $(W) = 2.61N$



**Figure 6: Dimension of screw shaft**

By considering vertical plane (X) horizontal plane (Y),

Total bending moment  $(M_i)$

$$M_{BTotal} = \sqrt{(My)^2 + (Mx)^2} \quad (1)$$

$$M_{BTotal} = \sqrt{(0.5)^2 + (0.38)^2}$$

$$M_{BTotal} = 0.63Nm$$

Twisting moment  $(T) = 15.56N$

When the shaft subjected to combine twisting moment and bending moment,  $K_m$  and  $K_t$  values are obtained by data sheet of load applied gradually in rotational shaft.

$$K_m = 1.5$$

$$K_t = 1.0$$

Yield strength of Stainless steel 304,  $\sigma_{yt} = 215MN/m^2$

Equivalent shear stress  $\sigma_{eq} = \frac{16}{\pi d^3} \left[ k_m M + \sqrt{(K_m M)^2 + (K_t T)^2} \right]$  (2)  
 $(\sigma_{eq}) = 21MN/m^2$

Allowable bending stress  $\sigma_b = 0.6 \times \sigma_{yt}$   
 $\sigma_b = 129MN/m^2$

25% reduction  $\sigma_b = 96.75MN/m^2$

$\therefore \sigma_b > \sigma_{eq}$

Equivalent shear stress  $\sigma_{eq} = \frac{16}{\pi d^3} \left[ (k_m M)^2 + (k_t T)^2 \right]^{1/2}$  (3)  
 $(\sigma_{eq}) = 19MN/m^2$

Allowable shearing stress  $\sigma_s = 0.3 \times \sigma_{yt}$   
 $\sigma_s = 64.5MN/m^2$

Reducing by 25%  $\sigma_s = 48.38MN/m^2$

$\therefore \sigma_s > \sigma_{eq}$

Therefore, the shaft material would have an equivalent shear stress of  $\sigma_{eq} = 21MN/m^2$

Diameter of the shaft =  $16 \times 10^{-3}m$

Length of the shaft =  $400 \times 10^{-3}m$

Material = Stainless steel 304

Bearings = Stainless steel deep groove ball bearings (W6202ZE, W6301ZE)

### 3.3 Sliding shaft calculations

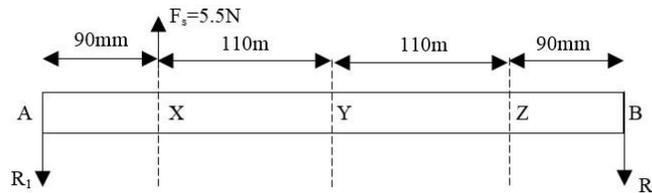


Figure 7: Bending moment diagram

Figure 7 given above shows bending moment diagram and Figure 8 given below shows the sliding shaft geometry.

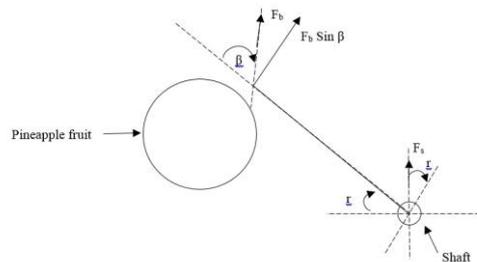


Figure 8: Sliding shaft geometry

By considering vertical plane (X) horizontal plane (Y),  
Total bending moment ( $M_t$ )

$$M_{BTotal} = \sqrt{(My)^2 + (Mx)^2} \quad (4)$$

$$M_{BTotal} = \sqrt{(-0.55)^2 + (-0.44)^2}$$

$$M_{BTotal} = \underline{\underline{0.7Nm}}$$

The shaft subjected to bending only,

$$\text{Minimum diameter of the shaft } d^3 = \frac{0.7 \times 32}{\pi \times 215 \times 10^6}$$

$$d = 3.2 \times 10^{-3} m$$

Diameter of the shaft =  $15 \times 10^{-3}m$   
 Length of the shaft =  $400 \times 10^{-3}m$   
 Material = Stainless steel 304

### 3.4 Calculations of the shaft holding the pineapple fruit

Consider of small  $\theta$  angle rotation of the system  
 G - Modulus of rigidity  
 L - Length of the shaft  
 d - Diameter of the shaft

$$L = L_1 \left( \frac{G}{G_1} \right) \left( \frac{d}{d_1} \right)^4 + L_2 \left( \frac{G}{G_2} \right) \left( \frac{d}{d_2} \right)^4 \quad (5)$$

$$400 = 220 \left( \frac{77.2 \times 10^9}{0.002 \times 10^9} \right) \times \left( \frac{d}{d_1} \right)^4 + 140 \times (1)$$

$$d = \underline{\underline{9.7 \times 10^{-3} m}}$$

Material of the shaft = Stainless steel 304  
 Diameter of the shaft =  $15 \times 10^{-3} m$   
 Length of the shaft =  $140 \times 10^{-3} m$   
 Bearing = Stainless steel deep groove ball bearing 6202-2RS

### 3.5 Gear calculations

The gear ratio between worm shaft and pineapple fruit attached, was assumed as = 1:1

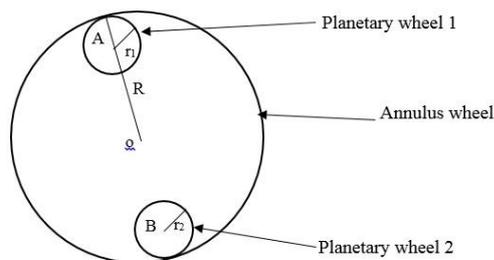


Figure 9: Internal gear meshing system

$r_1$  - radius of planetary gear 1 (pineapple fruit)

$r_2$  - radius of planetary gear 2 (worm shaft)

R - Radius of annulus

D - Diameter of annulus

$$r = 18.75 \times 10^{-3} m$$

$$R = 93.75 \times 10^{-3} m$$

Take the module  $= 2 \times 10^{-3} m$

Number of teeth in annulus ( $T_A$ )  $= 93.75$

$$= 100$$

Number of teeth in planet gear ( $T_p$ )  $= 18.75$

$$= 20$$

Therefore, Radius of annulus taken as (R)  $= 100 \times 10^{-3} m$

$$= \frac{100}{5}$$

Radius of planetary gears ( $r_1, r_2$ )

$$= \underline{\underline{20 \times 10^{-3} m}}$$

### 3.6 Strength calculation for internal mesh gear

Considering planetary gear 1 and annulus

Tangential force (fr)  $= 34.92N$

Therefore, Torque on the shaft ( $\tau$ )  $= 0.34 Nm$

Tangential tooth load on planetary 1 ( $Ft_1$ )  $= 26.18N$

Assume the angular velocity of the ring gear  $w_2 = 2\pi rad s^{-1}$

Therefore, pitch line velocity (V)  $= 0.628 ms^{-1}$

Velocity factor ( $C_v$ )  $= 0.827$

Ultimate tensile stress of stainless steel 304 ( $\sigma_{ut}$ )  $= 505 MPa$

Lewis form factor (Y)  $= 0.152$

$$\therefore Ft_1 = \sigma \omega \times b_1 \times \pi \times m \times y \quad (6)$$

Face width of planetary gear 1,  $b_1 = \underline{\underline{3.9 \times 10^{-4} m}}$

Similarly,

Face width of planetary gear 2,  $b_2 = \underline{\underline{1.22 \times 10^{-5} m}}$

Therefore, the minimum face width of planetary gear wheels will be  $3.9 \times 10^{-4} m$  and  $1.22 \times 10^{-5} m$ .

Total torque on (annulus) hand  $(\tau_T) = Ft_1 \times R + Ft_2 \times R \quad (7)$

$$\tau_T = 100 \times 10^{-3} [6.18 + 1.54]$$

$$\tau_T = \underline{\underline{2.772 Nm}}$$

### 3.7 Dynamic torque load calculations ( $F_D$ )

Total dynamic load ( $F_D$ )  $= 922 kg$

Static tooth load ( $F_S$ )  $= 13971 kg$

Wear tooth load ( $F_W$ )  $= 829 N$

Here the values are satisfied the conditions,  $F_D < F_S$  and  $F_D < F_W$

( $D_R$ ) Diameter of annulus  $= 200 \times 10^{-3} m$

( $D_p$ ) Diameter of planetary  $= 40 \times 10^{-3} m$

Number of teeth in annulus ( $T_A$ )  $= 100$

Number of teeth in Planetary ( $T_P$ ) = 20  
 Face width (b) =  $35 \times 10^{-3}$  m  
 Ratio of gear = 5

## 4 RESULTS AND ANALYSIS

### 4.1 Volume comparison of pineapples before and after peeling

The initial volume of 10 pineapples before peeling and the final volume after peeling by the designed machine are presented in Table 3.

**Table 3: Initial volume and final volume of pineapples peeled by the machine**

Pineapple	Initial volume of pineapple fruit (cm <sup>3</sup> )	Final volume of pineapple fruit (cm <sup>3</sup> )
1	993	837
2	1047	896
3	1070	933
4	1076	953
5	1090	970
6	1115	972
7	1124	1007
8	1148	1034
9	1150	1010
10	1180	1016

The initial volume of 10 pineapples before peeling and the final volume after peeling by labours of the company are presented in Table 4.

**Table 4: Initial volume and final volume of pineapples peeled manually by labours**

Pineapple	Initial volume of pineapple fruit (cm <sup>3</sup> )	Final volume of pineapple fruit (cm <sup>3</sup> )
1	997	783
2	1009	772
3	1014	793
4	1093	845
5	1103	780
6	1107	737
7	1127	797
8	1172	830
9	1184	854
10	1203	803

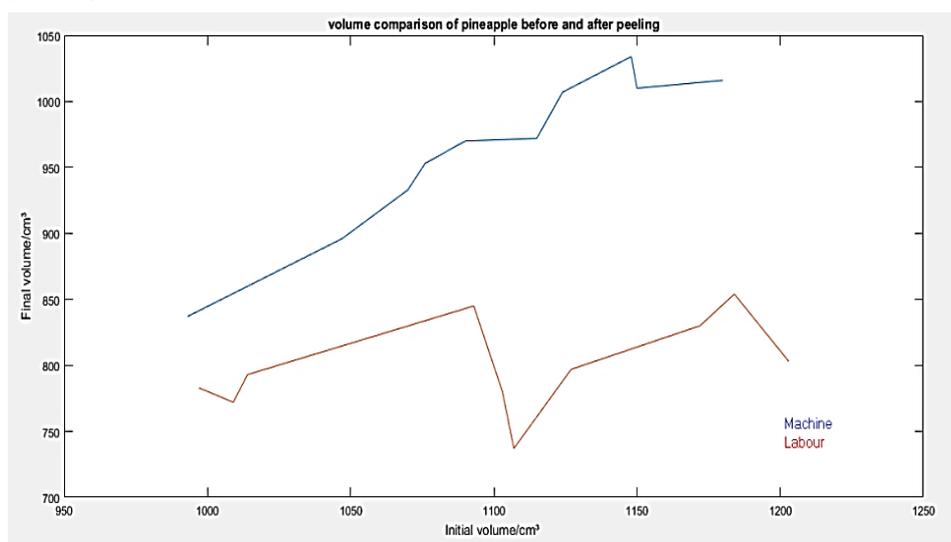
## 4.2 Saved meat wastage

The amount of saved meat wastage is shown in Table 5. From 10 pineapples, 1634 cm<sup>3</sup> amount of meat was significantly saved using the machine instead of labourers.

**Table 5: Result of saved meat wastage**

Peeled pineapple volume by machine (cm <sup>3</sup> )	Peeled pineapple volume by labourers (cm <sup>3</sup> )	Meat wastage (cm <sup>3</sup> )
970	772	198
1010	780	230
1016	830	186
972	797	175
953	845	108
1034	854	180
837	737	100
933	803	130
1007	783	224
896	793	103
TOTAL VOLUME OF SAVED MEAT		1634 cm <sup>3</sup>

Volume comparison of the pineapples volume before and after peeling using the peeling machine and labourers are displayed in Figure 10. By using the volume comparison method, the saved meat wastage was clearly observed and identified as 1634 cm<sup>3</sup>. In Figure 10, the volume comparison is displayed as the difference between the area under two curves in graph. The data as calculated volumes are indicated in the Table 5. In conclusion, as the Figure 10 represents, the meat wastage was found as 1634 cm<sup>3</sup> (Approximately 1.5 pineapples) were saved from 10 pineapples by using the designed pineapple peeling machine.



**Figure 10: Volume comparison of pineapples before and after peeling**

## 5 DISCUSSION

The machine can perform the major functions of peeling pineapples mechanically and safely. All the aspects considered in the design of the machine has been achieved in order to minimise meat wastage. In this pineapple processing machine; when the arm moves towards right end, it is not necessary to move the arm to its initial position. Rotating is done manually. A huge work load is gained by a simple and slight movement. The developed machine will enable peeling different sizes of pineapples by the adjusted constant thickness of the peeling and by the action of the tensioned spring in the cutting arm, allowing the pineapples to be peeled in curve shape. The cost of production was slightly high due to high fabrication costs of gear wheels and thread bars. The manufacturing costs are high due to the machining costs of the components. However, the present design can be improved further, to enable practical usage at a minimal cost.

The machine was completely designed and developed to be operated mechanically. However, if the machine can be automated using necessary technologies and improvements; the efficiency can be increased more.

The Machine can be considered as a user-friendly machine since requires less space and have the ability to disassemble parts. Also, the control movements are simple and easy to perform due to the simplicity of the mechanism. The construction and the parts are easily configured or replaced. Moreover, the machine is smoothly finished and easily cleaned. Final dimensions of the machine are 300mm width, 400 mm length and 220 mm height. The stand is 900 mm. The weight of the machine is 10 kg and the stand is 6.5 kg. Thus, the total weight is 16.5 kg. Therefore, it is easy to handle. This pineapple peeling machine can increase the overall pineapple production of the company by increasing the efficiency. Furthermore, this can be used as a platform to carry out further experimentations and developments in order to enhance its efficiency.

## 6 CONCLUSION

The conventional pineapple peeling process of the company according to the experiments carried out, takes about 5.56 hours to peel and dice 3333 pineapples by one labourer. That is, it takes 60 seconds to peel a pineapple by one labourer. The machine takes 20 seconds to peel one pineapple by one operator. The ease of operation of this pineapple processing machine enables an operator to peel the total capacity of pineapples per day (about 3333 pineapples) in less than 1.85 hours approximately. Precisely it achieves the objective; to save time by reducing the time taken to peel one pineapple fruit of the existing pineapple processing setup.

The existing process of the company requires 10 labourers to achieve their target for a day. The machine only needs one operator to carry out the peeling process. In order to accomplish the target of the day, it may need about 3 or 4 labourers. However, the implementation of the machine will significantly reduce the labour requirement for the peeling process by achieving the objective reducing the labour requirement.

Moreover, reducing the meat wastage was a significant factor to increase the output. Suitable techniques were included to machine designing after observing the waste development of the current process. The saved meat wastage was found by the volume difference of peeled pineapples by labourers and the machine. From 10 pineapples, 1634 cm<sup>3</sup> worth of meat wastage was significantly saved using the machine instead of

labourers. Therefore, the quantity of the production may possibly be increased by the reduction of waste production, thus it accomplishes the objective of increasing the quantity of the production by minimizing the meat wastage.

So far, for the recommendations and implementations, the machine peels a pineapple only when the arm moves towards the right side and there is no peeling of pineapples when the arm moves from right to left. Future work can be done to peel a pineapple when the arm moves from right to left side as well by using a dual threaded bar. This development possibly will increase the efficiency of the process since it is an optimum way to double the efficiency.

## 7 ACKNOWLEDGEMENT

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