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Design of A Vertical Conveyor System for Scrap Rubber in FGV Felda Rubber Industry

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Abstract: The vertical conveyor system is a mechanical system that can be used to convey the product from a level to another level. In FGV Rubber Industry, the manual conveying method is costly and low productivity. Therefore, this project aims to design a conveyor system that could help the requestor to achieve the expected daily production capacity as requested by the industry. The whole design process stage of the conveyor system was modified by referred to the Pahl & Beitz design process while the design analysis of the screw conveyor system was referred to the engineering guide from KWS Manufacturing Company. In this project, the designed machine was focused on the requirement listed by the requestor and fulfill the technical needs of the industry. The simulation and project drawing were outlined and determined by SolidWorks software. The production capacity of designed machine is approximately 107.69 tons/hr.

Keywords: Scrap Rubber, Vertical Conveyor System Design

1. Introduction

In Malaysia, the agriculture tree crops are one of the main incomes of our country by exporting these products that include rubber, oil palm, coconut, and cocoa. It had covered about 4.82 million hectares approximately in Malaysia while the rubber tree is the most contributed and most economically important among these crops [1]. The harvested solidified latex will transfer to the rubber industry for further processing.

In FGV Rubber Industry, the actual processing step is semi-automatically. Firstly, the rubber will be blended into small pieces by using the jumbo cutter in the blending area and this process is carried out automatically by the cutting machine (Refer to Figure 1 (A)). After that, the scrap rubber which is the small rubber after cutting will be transferred to the ponds for the washing process. This moving process is fully manual by using the excavator truck (Refer Figure 1 (B)). Figure 2 shows the layout of FGV Rubber Industry and the location of different conveyor systems. The current method to carry the scrap rubber from loading area to ponds is costly and low productivity. At the same time, there are many potential risks faced by employee during the carrying process.

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The objective of this project is to design a conveyor system that can transfer the scrap rubber after cutting to the loading area which connected with next conveyor belt in FGV FELDA Rubber Industry. The vertical conveyor system should be able to convey the scrap rubber with average size 5.75 inches with 10-meter elevation height. The scope of this project is to Design a vertical conveyor system with approximately 10 meters height and 18.15 meters length that able to transfer the scrap rubber at the minimum flow rates of 10 tons/hour. Next, make the 3D model, conduct the simulations, animation, and complete the project drawing of the conveyor system by using SOLIDWORKS software. The third scope of study is ensuring the conveyor system have a maintenance platform with rooftop.

Figure 1: Scrap Rubber Moving Process (A, B)

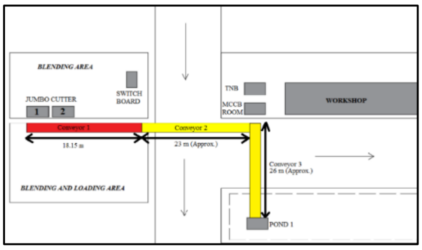

Figure 2: Layout of FGV Rubber Industry

2. Literature Review

Literature review is a survey or study on the scholarly source on the related topic and area. The scientific journal, engineering guide, and current existing catalogue would be used to gather the information as well as determine the suitable design knowledge on solving problems.

2.1 Study on Types of Conveyors

A vertical conveyor is used to convey the product from one level to another level and basically connected with a horizontal conveyor to continue the product conveying process horizontally [2]. There are few types of vertical conveyors suitable for this project which are belt conveyor, bucket elevator, and screw conveyor.Belt conveyor is the common tool used to carry the bulk materials in the industrial by an endless loop carrying mechanism which mainly used in the food industrial, non-food industrial, packaging sectors, and general materials handling for storage and distribution. Refer to the Figure 3, when the inclination angle is increase, the tractive ability of the drive to the inclination belt will decrease so the efficiency of the belt conveyor will decrease [3].

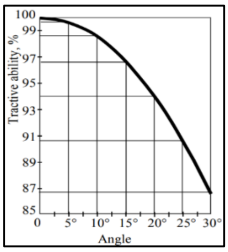

Figure 3: Tractive Ability of Conveyor Relative to Inclination Angle

Bucket elevator is the common type of vertical or inclined material handling equipment that using the bucket mounted on the endless belt or chain to convey the bulk material [4]. The advantage of choosing the bucket elevator is because it could convey a wide variety of bulk materials by changing the bucket size based on the bulk material characteristics. Oppositely, it also easy to plug due to the overload situation and the hopper section is easy to wear so the maintenance cost is very expensive. For the belt type bucket elevator, the material could be jammed in the space between the belt and the back of the buckets and caused the damage [5].

The mechanism of the screw conveyor is based on the rotating shaft inside the trough (tube) which coiled with a helical screw blade. The rotating shaft is driven at one end and held at the other. The material will be poured into the inlet chutes the rotating shaft which coiled with a helical screw blade will carry the material to the end of the tube and exit and the outlet chutes. Refer to Figure 4, the higher the inclination angle, the lower the efficiency of the screw conveyor [6].

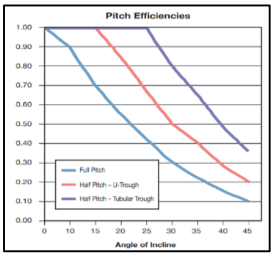

Figure 4: Pitch Efficiency Chart

By considering the bulk material properties of scrap rubber and also the production capacity requirement, screw conveyor system is more suitable for the application in FGV Rubber Industry since it was maintenance-friendly, able to convey wide variety of bulk material, and low maintenance fee required.

2.2 Study on Screw Conveyor Design Steps

The screw conveyor design steps were referred to the engineering guide developed by the KWS Manufacturing Company. Refer to Figure 5, the analysis flow chart of the screw conveyor and maintenance platform design steps were summarized. The standards components of screw conveyor and geared motor were selected on the product catalog developed by the KWS Manufacturing Company and Motovario Company, respectively [7]. Therefore, the stair treads and the beams selected for the maintenance platform were chosen from the product catalog from Ohio Grating Industry and Soon Hoe Steel Sdn. Bhd, respectively.

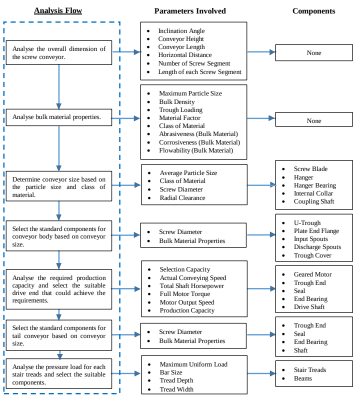

Figure 5: Analysis Flow Chart

3. Design Process and Development

Design of a conveyor system is considered as selection design since the standard components were selected from the manufacturer's catalogs to fulfil the requirements [8]. Therefore, the design stages of this project were modified the Pahl & Beitz design process model with the concept of selection design. The modified design process had illustrated in figure 6. There are totally 4 phases in the design process and the following sub-topic discussed the design process based on 4 phases.

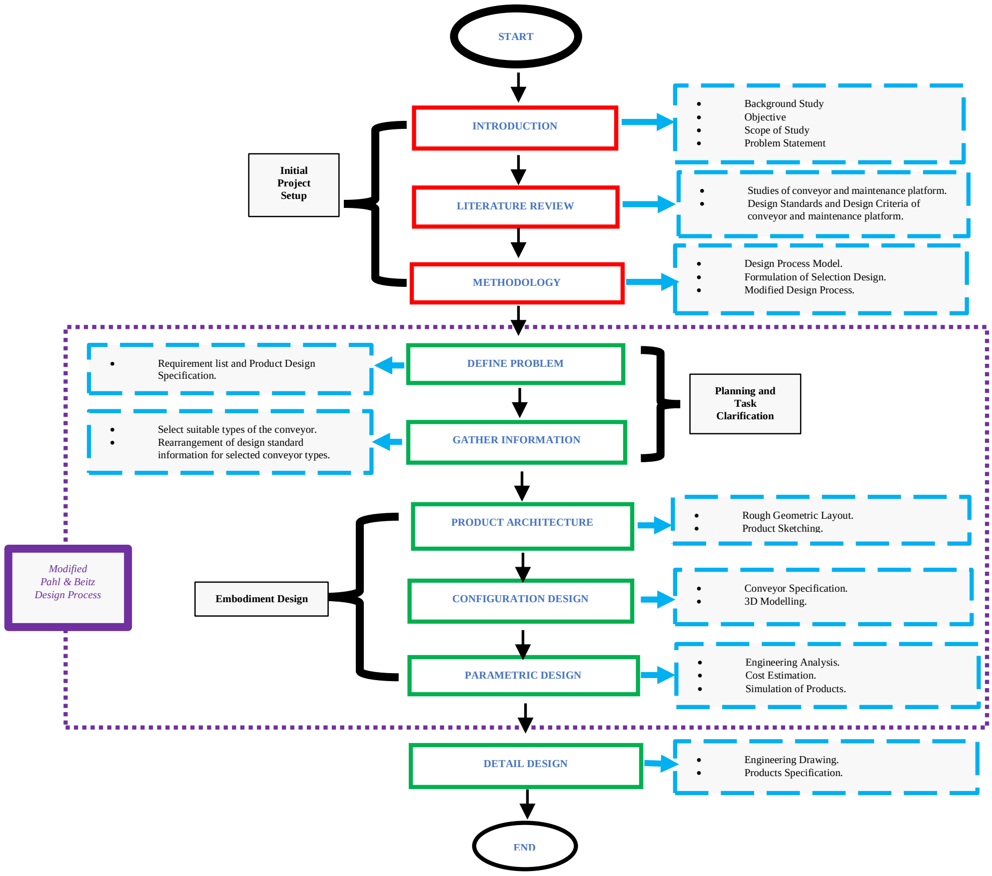

Figure 6: Flow Chart of Design Process

3.1 Requirement Lists (PDS)

In the first phase, the related information which required to use in this project were documented like background of the project, design process model, studies on the related knowledge of the design criteria for the conveyor, and maintenance platform. In the second phase (planning and task clarification), requirement list was tabulated, and all information collected in literature review steps were gathered. Figure 7 and 8 shows the requirement lists (product design specification) requested by industry.

FGV FELDA Rubber Industry	Product Design Specification for a Inclined Screw Conveyor	Issued on 03/03/21 Page: 1
Product Description		
• Inclined Screw Conveyor • Design Problem: Design a vertical/inclined conveyor system to replace the manual conveying method. • Function: Convey the rubber lump after cutting process to the next conveyor system. • Special features: (i) Automated System (ii) Available of Maintenance Platform • Service Environment: (i) Standard Outdoor Temperature (No extreme temperature)		
Requirement Lists		
Changes	**D W**	**Requirements**
		1. Physical Description
		(i) Inclined Screw Conveyor
	D	• Length ≈ 18.15m.
	D	• Height ≈ 10m.
	W	• Inclination angle between 20° and 30°.
	D	• Standard U-trough.
		(ii) Maintenance Stairway
	D	• Width of both side maintenance stairway ≥ 600mm.
	D	• Clearance between the stairway and handrail ≥ 550mm.
	D	• Depth of the tread ≥ 185mm.
	D	• Tread gap ≤ 30mm.
	W	• Used of checkered plat for treads.

Figure 7: Requirement List

		2. Functional Performance
	D	• Production capacity ≥10 tons/hour.
	D	• The conveyor able to convey the scrap rubber with size range between 4 inches to 8 inches.
	D	• Avoid the slip-back condition of rubber during the conveying process which could cause flooring at the lower end of conveyor.
	W	• Achieve conveying efficiency ≥ 60%.
	W	• Power consumption should be less than 20kW.
	D	• Used of 3-phases induction motor.
		3. Maintenance, Repaire, and Retirement
	D	• Friendly for routine maintenance process.
	D	• Used of standard parts and components that easy to obtain.
	W	• Screw blade section are designed to be easy to assemble and disassemble.
	W	• Conveyor system should have lifespan of more than 5 years.
	D	• Required rooftop for the maintenance platform.
		4. Safety
	D	• The inclined screw conveyor is stable and without any major failure occurs within its economic life.
	D	• Maintenance platform (stairway) should be anti-slip to prevent accident.
	D	• Safety factor of system ≥ 4.5.
		5. Economic
	W	• Low maintenance fee.
	W	• Production cost should be less than RM100000.

Figure 8: Requirement List (Continued)

3.2 Full Assembly of the Conveyor

During the third phase (embodiment design phase), the roughly layout of the conveyor will be determined first. After that, the types of the standard components were selected by considering the application in FGV Rubber Industry. The 3D model for these components were developed by using SolidWorks software. The standard components of inclined screw conveyor are distributed into 4 parts which are conveyor body, screw segment, tail conveyor, and head conveyor (drive end). The non-standard components are included with supporting frame, maintenance platform, and hopper. Refer to Figure 9, the components tree diagram shows all of the assembly and parts of the inclined screw conveyor with maintenance platform. Figure 10 shows the 3D model of inclined screw conveyor with maintenance platform.

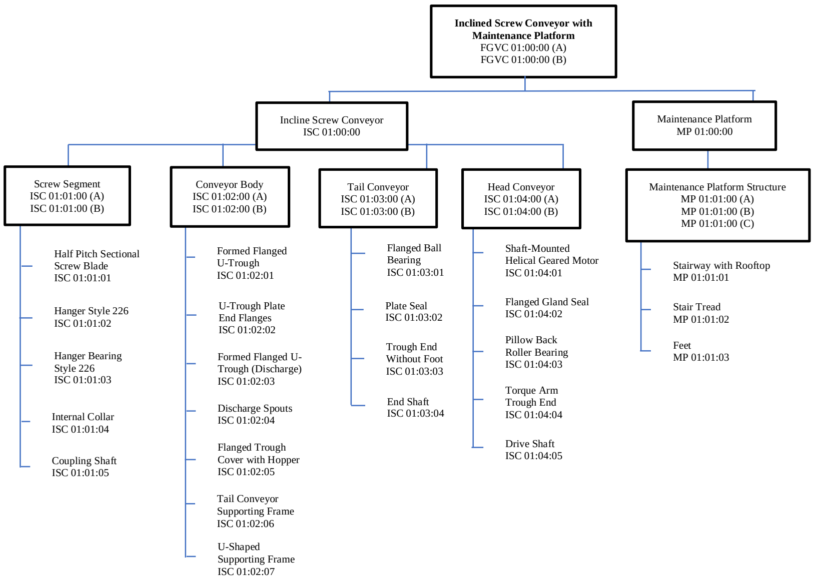

Figure 9: Components Tree Diagram

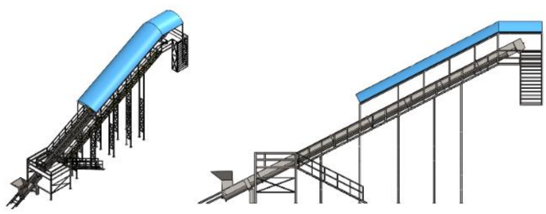

Figure 10: Full Assembly of Inclined Screw Conveyor with Maintenance Platform

3.3 Engineering Analysis

Based on the analysis flow chart that was discussed in **Subtopic 2.2,** the information required, parameter involved, and components selected for each of the steps were listed. Firstly, the requirement production capacity of inclined screw conveyor is 10 tons/hour while the bulk density of scrap rubber is 61 lbs./ft^3 which is equal to 977.1285 kg/m^3. The required capacity of the conveyor is evaluated by follow:

$$Capacity, CFH \left(\frac{m^3}{hr}\right) = \frac{Production\ Capacity \left(\frac{kg}{hr}\right)}{Bulk\ Density \left(\frac{kg}{m^3}\right)} \qquad \textit{Eq. 1}$$

$$= \frac{10 \times 1000}{977.1285} = 10.234\frac{m^3}{hr} = 361.414\frac{ft^3}{hr}$$

After the capacity is obtained, the selection capacity was calculated to determine the suitable screw conveyor diameter and speed in the capacity table. Since the capacity factor is 2.00 for half pitch screw so the selection capacity is calculated as:

$$SC = CFH \times CF \qquad \textit{Eq. 2}$$

$$Selection\ Capacity\ (SC) = (361.414 \times 2.00)\frac{ft^3}{hr}$$

$$Selection\ Capacity\ (SC) = \mathbf{722.828}\frac{\boldsymbol{ft^3}}{\boldsymbol{hr}}$$

The selection capacity was used to select the proper conveyor speed from the Capacity Table [6]. The conveyor speed was chosen based on the recommended trough loading % which suggested in the bulk material properties table. While the selection capacity must not exceed the maximum capacity given in the capacity table. The selection capacity is 722.828 ft^3/hour while the capacity at maximum RPM is 7085 ft^3/hour. Since the selection capacity is less than capacity at maximum RPM, so it is reliable. Based on the KWS Engineering Guide, the actual conveying speed is calculated by dividing the selection capacity by the capacity at 1 RPM which is formulated as:

$$Actual\ Conveyor\ Speed\ (S) = \frac{Selection\ Capacity\ \left(\frac{ft^3}{hr}\right)}{Capacity\ at\ 1\ RPM} \qquad \textit{Eq. 3}$$

$$Actual\ Conveyor\ Speed\ (S) = \frac{722.828}{109.0}$$

$$Actual\ Conveyor\ Speed\ (S) = \mathbf{6.631}\ \boldsymbol{RPM}\ (\boldsymbol{minimum})$$

6.631 RPM is the minimum actual conveyor speed which required to convey the scrap rubber in capacity of 722.8206 cubic feet per hour. The minimum conveying speed and selection capacity are important to determine the friction horsepower (FHP) and material horsepower (MHP) which are formulated as:

$$FHP = \frac{DF \times HBF \times L \times S}{1000000} \qquad \textit{Eq. 4}$$

$$FHP = \frac{235 \times 1.0 \times 75 \times 6.631}{1000000}$$

$$FHP = \mathbf{0.11687}$$

$$Where\ CP = Density\ \times Selection\ Capacity,$$

$$CP = 61\frac{lbs}{ft^3} \times 722.8206\frac{ft^3}{hr} \qquad \textit{Eq. 5}$$

$$CP = 44092.1\frac{lbs}{hr}$$

$$MHP = \frac{CP \times MF \times L}{1000000}$$

$$MHP = \frac{44092.06 \times 1.5 \times 75}{1000000}$$

$$MHP = \mathbf{4.96036}$$

While the material horsepower (MHP) had to corrected by using corrected MHP Chart [6]. The corrected MHP is approximately 4.85 when the calculated HP is around 4.85. After that, the total shaft horsepower (TSHP) was calculated by summing friction horsepower (FHP) and material horsepower (MHP). The incline factor (Fi) is 1.73 for 27 degree of inclination angle [6]. While the efficiency of motor (e) is generally 0.88 for 3-phases motor [6].

$$TSHP = \frac{FHP \times (MHP \times Fi)}{e} \qquad Eq.\ 6$$

$$TSHP = \frac{0.11687 + (4.85 \times 1.73)}{0.88}$$

$$TSHP = \mathbf{9.66747\ HP}$$

$$Since\ 1\ HP = 745.7\ W$$

$$TSHP = 7209.03\ W$$

$$TSHP = \mathbf{7.20903\ kW}$$

The minimum horsepower to initiate the application is 9.66747 HP, so this is the minimum horsepower which had to choose in the motor selection step. Among many different types of motor, shaft mounted geared motor are the most common types of motor which used for incline conveyor application. There are few steps of analysis before select the suitable geared motor (refer to Figure 11). The service factor (s.f.) is the first parameter to determine before choosing the horsepower. This parameter is depending on the type of load and frequency of motor of this application.

Geared motor selection

1. Determine the application's actual service factor **(s.f.)**. This parameter depends on the type of load of the powered machine, the number of starts per hour and the hours of operation (refer to the "Service factor" paragraph).
2. Calculate the input power $\mathbf{Pr_1}$ using the required torque value $\mathbf{Mr_2}$, the speed $\mathbf{n_2}$ and dynamic efficiency value. $\mathbf{Pr_1=(Mr_2*n_2)/(\mu_d*63.025)}$. The dynamic efficiency value depends on the type of gear reducer and on the number of gear reduction stages. (To calculate the efficiency value see its page).
3. Consult the geared motor performance tables and identify a normalised power value $\mathbf{Pn_1}$ exceeding the required power $\mathbf{Pr_1}$, such that: $\mathbf{Pn_1 \geq Pr_1}$
4. Once the suitable nominal power has been identified, select the geared motor capable of generating the rotational speed closest to the desired n_2 value and with service factor s.f. greater or equal to that required by the application.

Figure 11: Geared Motor Selection Steps

Based on the application in the industry, the type of load of the operated machine is Uniform Load (A) while the length of daily operating time (hours/day) is assumed approximately 8 hours with a 50 Hz start-up frequency. So, the final service factor is 1.3 which is determined by using the service factor chart from Motovario Product Catalogue [9]. After that, determine the required input power (motor) to obtain the minimum power required to initiate the shaft motion which known as total shaft horsepower (TSHP). Based on the carbon steel torque table in engineering guide, the output torque of the motor must below 24700 In-Lbs (lowest torque in table) to make sure the screw conveyor could function in safe condition [6]. While the desired output speed is 30 RPM and the dynamic efficiency for the 3-stages induction motor is 0.94. So, the required input power is calculated:

$$Pr_1 = \frac{(Mr_2 \times n_2)}{(\mu_d \times 63025)} \qquad Eq.\ 7$$

$$Pr_1 = \frac{(24700 \times 35)}{(0.94 \times 63025)}$$

$$Pr_1 = \mathbf{14.5923\ HP\ (Maximum)}$$

$$Pr_1 = \mathbf{10\ HP\ (Recommended)}$$

There are 14.5923 HP input power is required to initiate the shaft motion with 24700 torque value (maximum torque value) with 35 RPM so 10 HP geared motor is recommended. After that, calculate the normalized input power (Pn_1) labelled on the chosen motor nameplate must exceed or equal to Pr_1. Based on the nominal power table in product catalogue, 132M and 132MA is suitable for this application [9]. The overall requirements to select the most suitable geared motor after calculation were listed. The selected motor must have output speed around 35 rpm which could generated an output torque that below 24700 In-Lbs. The service factor of the motor must be 1.3 while the normalized power selected must less than 14.5923 HP.

The geared motor selected are 10 HP with 35.7 rpm of output speed. Based on the KWS Engineering Guide, the checking of full motor torque of the selected geared motor is calculated as:

$$Full\ Motor\ Torque = \frac{HP \times 63025}{S} \qquad Eq.\ 8$$

$$Full\ Motor\ Torque = \frac{10 \times 63025}{35.7}$$

$$Full\ Motor\ Torque = \mathbf{17654.06\ In - Lbs}$$

Since the full motor torque is less than 24700 In-Lbs so the motor selected was reliable. Based on the selected geared motor, the output speed is 35.7 rpm where the production capacity is 109ft^3/hr at 1 RPM, so the production capacity of the conveyor is formulated as:

$$Production\ Capacity = \left(109 \frac{ft^3}{hr} \times 35.7\ RPM\right) \times Density \qquad Eq.\ 9$$

$$Production\ Capacity = 3891.3\ \frac{ft^3}{hr} \times 61 \frac{lbs}{ft^3} = 237369.3 \frac{lbs}{hr} = \mathbf{107668.90 \frac{kg}{hr}}$$

3.4 Engineering Drawing

Engineering drawing for inclined screw conveyor with maintenance platform were developed by using SolidWorks software with bill of material and dimension. The details of each of the components and assemblies were listed in the drawing like dimensions, material, and standard part information. Figure 12 shows the full assembly for the overview design of the inclined screw conveyor with maintenance platform.

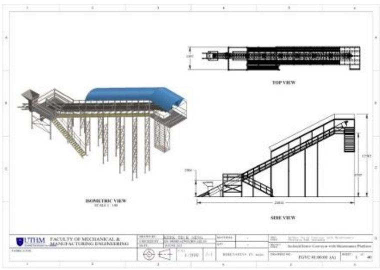

Figure 12: Full Assembly Drawing

3.5 Simulation of Product

Simulation is carried out to predict the product's real-world behaviour by testing the CAD model with real conditions. The simulation analysis was conducted by using computer-aided software, SolidWorks. During this analysis, screw blade and maintenance platform will be analysed. This simulation results will be used to determine whether this product is safety enough.

3.5.1 Simulation of Screw Conveyor Blade

The loading of the scrap rubber in the inclined screw conveyor is recommended as 30% which is mentioned in bulk material properties table. The volume of the scrap rubber in the conveyor must be calculated first before determining the weight of the scrap rubber. The calculated weight of conveyed scrap rubber which exerted on each screw blade revolution is 93.48kg. So, there are total 918.12N of force exerted on each of the screw blade revolution. In order to complete simulation, fixed geometry is set on the screw blade shaft while the external force is applied on the 30% of screw blade as shown in Figure 13. The results of the simulation are 44.1 MPa of maximum von mises stress and 5.7 of minimum factor of safety.

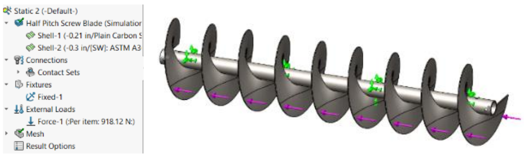

Figure 13: Fixed Geometry and External Load applied on Screw Blade

3.5.2 Simulation of Maintenance Platform

The maintenance platform was designed to support the inclined screw conveyor and also provide the stairway to allow the maintenance technicians access. The weight of screw conveyor with scrap rubber are the force exerted on the maintenance platform. There is total 3 rectangular beam used to support the weight for each screw conveyor segment with scrap rubber, so the total force exerted on each of the rectangular beam is 4397.37N since the weight of each segment are 1344.76kg. In order to complete simulation, fixed geometry is set as the joints at the bottom end of the supporting truss while the force exerted by the screw conveyor was set on the rectangular beam (refer to Figure 14). The results of the simulation are 41.1 MPa of maximum upper board axial and bending and 4.2 of minimum factor of safety.

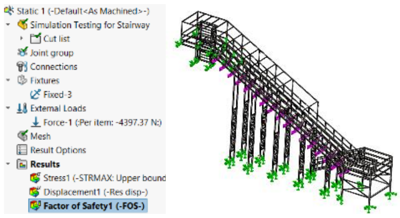

Figure 14: Fixed Geometry and External Load applied on Maintenance Platform

3.6 Animation of Scrap Rubber Conveying Process

The animation of conveying process was developed by using the motion analysis features in SolidWorks software. The scrap rubber after cutting process will be carrying to the hopper first (refer to Figure 15). While the scrap rubber will start to be conveyed from the tail conveyor to the head of the conveyor through the rotating mechanism of the screw conveyor blade (refer to Figure 16). At the head end of the conveyor, the scrap rubber will drop to the next conveyor system through the discharge spouts (refer to Figure 17).

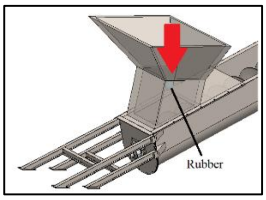

Figure 15: Rubber Poured into Hopper

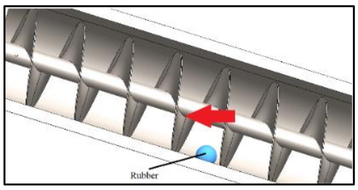

Figure 16: Rubber at the middle of conveyor

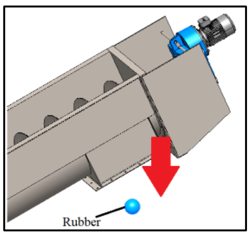

Figure 17: Rubber Drop to the Next Conveyor

3.7 Product Specifications

The finalized product specification was listed out for the further checking and review back for requirement lists. The overall product specifications of the inclined screw conveyor with maintenance platform were tabulated in Table 1.

Table 1: Product Specification

Overall Product Specifications	
Product Name	Inclined Screw Conveyor with Maintenance Platform
Overall Dimensions (L x W x H)	24038mm x 3440mm x 12607mm
Overall Weight	28916.92 kg
Overall Cost	≈RM511511.59
Production Capacity	≈107.69 tons/hr
Rotation Speed	35 RPM

4. Conclusion

In conclusion, the objective of this project is achieved. The design process for the inclined screw conveyor with maintenance platform is referred to the design model of Pahl & Beitz. The design standard of the inclined screw conveyor had referred to the engineering guide introduced by KWS Manufacturing Company. During every design process, every step was carried out by considering the requirement list. The final design of the inclined screw conveyor is able to convey the scrap rubber from the floor level to the next conveyor system on 10-meter height with 107.69 tons/hour of production capacity. The rotational speed of the screw conveyor to achieve this production capacity is 35.7 revolution per minutes. The overall dimension of the inclined screw conveyor with maintenance platform are 24.038m in length, 3.440m in wide, and 12.607m in height (included with rooftop). Overall weight of the designed machine is 28916.17kg and costed for RM511511.59 approximately.

Acknowledgement

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References

[1] M. N. Suratman, G. Q. Bull, D. G. Leckie, V. M. Lemay, P. L. Marshall, and M. R. Mispan, "Prediction models for estimating the area, volume, and age of rubber (Hevea brasiliensis) plantations in Malaysia using Landsat TM data," *Int. For. Rev.*, vol. 6, no. 1, pp. 1–12, 2004, doi: 10.1505/ifor.6.1.1.32055.

[2] Alphacon Solutions, "Vertical Conveyor Systems," 2017. https://alfaconsolutions.com/?portfolio=vertical-conveyor#:~:text=A vertical conveyor is a,of incline or lowering belts.

[3] S. A. Trufanova, I. S. and Lavrenko, "The efficiency improvement of belt conveyor intermediate drive traction effort," *ARPN J. Eng. Appl. Sci.*, vol. 11, no. 7, pp. 4317–4321, 2016.

[4] X. Xiong, Y. Gong, X. Wang, P. Dai, and X. Gong, "A design process to eliminate bucket-to-bucket interference on chain bucket elevator," *Adv. Mech. Eng.*, vol. 8, no. 9, pp. 1–6, 2016, doi:

10.1177/1687814016668104.

[5] F. R. of Rolf Kriger, Libeck and Germany, “Belt-Type Bucket Elevator,” US4770288, 1988.

[6] KWS Manufacturing Company Ltd., “Screw Conveyor Engineering Guide,” *ANSI Stand*, 2016, doi: 10.1007/978-3-642-41714-6_191009.

[7] KWS Manufacturing Company Ltd., “Screw Conveyors Component Guide,” *ANSI Stand*, 2016, doi: 10.1007/978-3-642-41714-6_191009.

[8] Rudolph J. Eggert, *Engineering Design*. Upper Saddle River, N.J. : Pearson/Prentice Hall, ©2005., 2005.

[9] Motovario S.p.A, “Shaft Mounted Geared Motor Series BF,” 2017.