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Design and Simulation of Cultivating Machine for Double Digging Planting Technique

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Abstract: Agriculture sector is a crucial sector that plays an important role on Malaysia economic. Malaysia agriculture farmers and gardeners facing the same problem when it comes to preparing crops soil where it consumes too many man hours to complete. Tillage needed to be implemented to the soil as preparation by mechanical agitation of various types such as digging, ploughing, overturning and stirring. Double digging is one of a new form of deep tillage where it utilizes compost and mulch to enhance crops productions. This study aims to increase soil drainage and aeration on two layers of various types of soil and to create a machine simulation model and design which will ease farmers loosing packed-soil during farming. In this context, a machine design and simulation will be made by using Solidworks 2020 software in order to obtain 3-dimensional product drawing. To test either the machine fail or success when operating, simulation need to be done to roughly see how the machine will buckle and bend when various types of load and stress applied on certain part of machine body frame. The results showed there will be a small amount of bending due to the weight of the machine motor and rigger. Plus, the materials chosen are compatible to handle all stress, strain and high factor of safety on the body frame.

Keywords: Cultivation, Double Digging, Machine

1. Introduction

Gardening is the practice of growing and cultivating plants as part of horticulture. Useful plants, such as root crops, leaf vegetables, fruits, and herbs, are cultivated for consumption, dyeing, or medicinal or cosmetic purposes. Since then, many gardening techniques has been developed by gardeners and gardening experts such as tillage, biodynamic, organic, hydroponic and aquaponics [1]. Almost twenty-four percent of Malaysia's land area is composed of land dedicated to agriculture. Around 43,000 different agricultural machines and tractors are available. There are 7,605,000 hectares of arable and permanent cropland in Malaysia. Every year, Malaysia produces 535,000 metric tons of bananas. Irrigation is used on only around 5% of Malaysia's cropland [2].

Plus, Malaysia usually exports one-third of the world's rubber. However, since most states are transitioning to a more lucrative commodity, palm oil, production of rubber has decreased. Malaysia

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exports a variety of goods, including timber, pepper, and tobacco. Malaysia's rubber production has increased steadily since 2001. In 2019, Malaysia's global agricultural trade totaled $43.5 billion, with $25 billion in exports and $18.3 billion in imports. Palm oil is the main export, and the top markets for this Malaysian commodity in recent years have included India, the European Union, China, Pakistan, and the United States. Thailand, Indonesia, and China are Malaysia's top agricultural product suppliers in 2019, with the United States coming in fifth. Despite a $6.7 billion agricultural trade surplus with the rest of the world, Malaysia still imports many primary items such as wheat, rice, protein meal, dairy products, beef, and the majority of deciduous and citrus fruits [2].

Usually during farming or gardening, deeper soil layers is compacted by heavy farm machinery or farmers stepping on the soil frequently. Tillage needed to be implemented to the soil as preparation by mechanical agitation of various types such as digging, ploughing, overturning and stirring. Deeper tillage and more thorough is crucial or primary where shallower and more selective of location is secondary. Primary tillage, such as ploughing, produces a rough surface finish while secondary tillage, such as that needed to make a good seedbed for many crops, produces a smoother surface finish. Moreover, agricultural expert proposed that the depth of ploughing should be at least 0.12 m to 0.20 m [3]Double digging is one of a new form of deep tillage where it utilizes compost and mulch for improved crop production. Compost is aimed at supplying or adding essential nutrients to the plants and improving soil physical properties during cultivating. Plus, mulch is aimed to preventing erosion, retaining soil moisture and reduces soil water loss by evaporation, limiting weed growth and improves infiltration [4].

In the past, it is found larger pore space on soils where it is not cultivated by ploughing tractors compared to the soils on mechanized farms. Agricultural expert, Russell, Hull and Webb have shown consistent enhancement in yield from sub-soiling [5]. Double digging machine is a tool for farmers and gardeners that will ease them to implement double digging technique during cultivating crops and in the same time increasing the crop production and quality compared to existing plough machine where it only achieved limited soil loosening effect and only loosen upper layer of soil.

Hence, agriculture sector is a crucial sector that plays an important role on Malaysia economic. Farming skills and techniques were implemented through direct learning and experience. Farmers in Malaysia need to register under Department of Agriculture Malaysia (DOA). More machines are required on various types of functionality depend on tillage techniques for farmers. Currently, there is no double digging machine invented or produced in Malaysia as demand of it is increasing throughout years. There are several constraints have been identified to design double digging machine:

i. There are several types of soil with different physical properties and porosity.

ii. Geometrical dimension of machine depends on size of cultivation.

Objective of this study is to increase soil drainage and aeration on two layers of various types of soil and to create a machine simulation model and design in which will ease farmers and gardeners loosing packed-soil during farming.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Materials

Material selection is an important part to design the product so that it will not fail when fabricated later. There are several types of aluminium, steel and rubber used in designing Double Digging Machine. The main suggested material to be used in making this machine is aluminium. The characteristic of the material which is high resistant to corrosion, high strength and easy machining are the reason why aluminium is chosen among the other materials. Plus, aluminium is a recommended material for agriculture purpose.

Table 1: List of Material

Name	Component Involved	Selection Factor
Aluminium 2024	Body Frame	Strong Resistant to corrosion
Steel AISI 1045	Rigger Blade	Strength Durability Ductility
Steel AISI 1020	Base Support	Strong Ductility
Natural Rubber	Tyres	Stiff High friction and abrasion resistance

2.2 Methods

Design process is the most important phase in manufacturing a product. In the designing process of double digging machine, convert the tedious manual method of subsoiling, digging and tilting the soil into mechanical and electrical method. The purpose is to cut down the operating cost and decreases the time consume when doing the process.

The main part of this machine is the blades which play a crucial role to dig and rotate the soil horizon. Here comes the part where the function of arranger is used. The soil will be arranged on the back side of machine frame and will come out as plant bed. The size of machine frame is determined by taking much aspect into consideration. That include the size of plant bed, motor and blades. The preliminary stage of any product design is the conceptual design phase. The early sketches of the machine are crucial in order to brainstorming ideas and making future improvement.

This study requires design software in order to execute product sketch ideas into 3-Dimesion drawing and simulation on product before fabrication process. Drawing is crucial as it translate the dimension of real product into software and the product geometrical dimension will be determined using parameters obtained. Hence, Solidworks 2020 software was used in order to obtain 3-dimension double digging machine drawing.

2.3 Design Selection

After going thru all the phases needed, the final design was chosen after considering several factors. The factors that need to be considered when selecting design are functionality, safety, material selection and size: In the early stage of this study, two design was proposed in order to make comparison on factors that stated before.

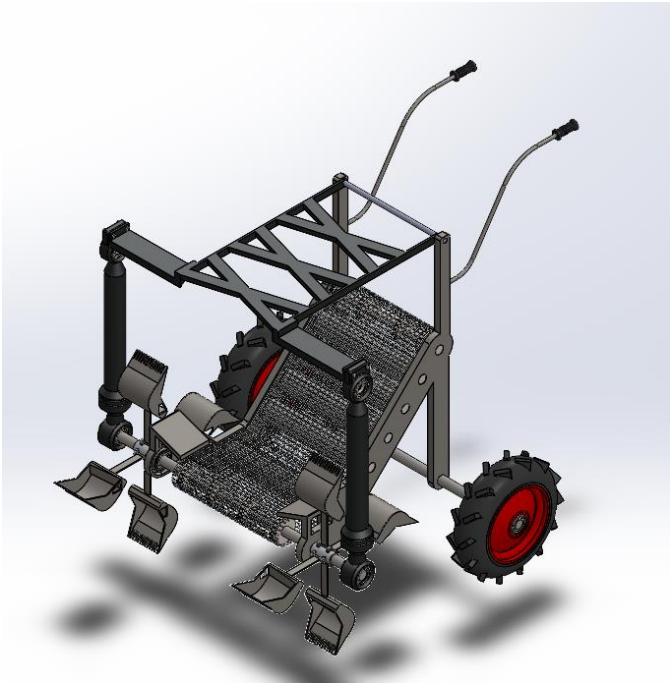

Figure 1: Design 1 proposal

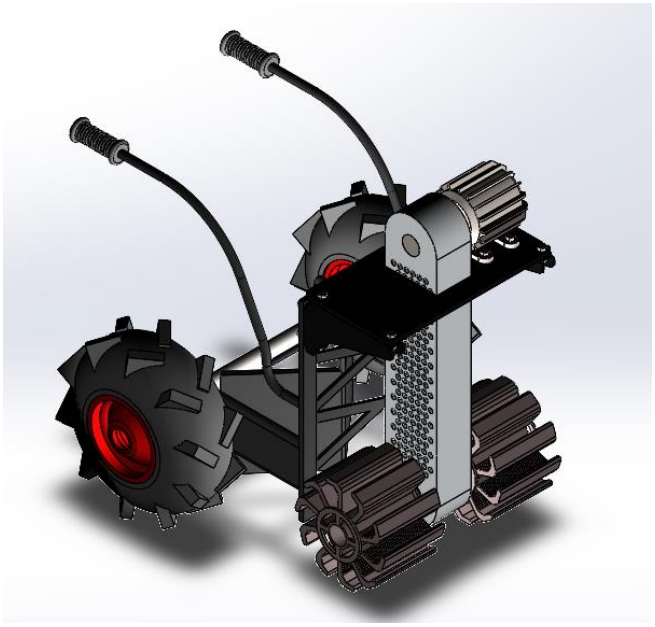

Figure 2: Design 2 proposal

Then, the second design was chosen to be further enhance, this is because the design meets and fulfilled almost all the factors that has been considered. Moreover, this machine design has a suitable mechanism concept which locate the rigger at the front bottom to obtain lower center of gravity.

3. Results and Discussion

The result obtain from this study are the calculation of torque, rotational speed, power, gear analysis, simulation of double digging machine and final drawing. The torque, rotational speed, power

and gear analysis is obtained by calculating the force needed to lift certain volume of soils. Furthermore, the simulation and final drawing of double digging machine is obtained through Solidworks 2020 software.

3.1 Torque, Speed and Power required

The value of torque, speed and power required is obtained by using formula shown in Eq. 1 to Eq. 3. This formula is used with gear ratio from motor to blade 1:10.

$$\tau_{Motor} = \frac{\tau_{Blade}}{10} \qquad Eq.1$$

$$N_{Motor} = 10\, N_{Blade} \qquad Eq.2$$

$$P_{req} = \tau\omega \qquad Eq.3$$

The value of torque required from the motor to rig the soil is 9.64 Nm. It can be obtained through Equation 1. Plus, the rotational speed (Eq. 2) is 333.33 rpm and the power required from DC motor is 336.47 W (Eq. 3). From the calculated result, the suitable motor specification is obtained. Hence, the motor can be drawn according to its size.

3.2 Gears and Shaft

In determining the exact gear set specifications from KHK bevel gears, calculation has been made in order to have overall gear length and to fit the gear at rigger shaft in the drawing. Table 2 shows several parameters on bevel gear set.

Table 2: Bevel Gear Specification

Parameters	Pinion	Gear
Shaft Angle, $\sum$	90 Deg	
Module, m	4	
Pressure angle, $\emptyset$	20	
Pitch Diameter, D_P	60	120
Reference Cone Angle, δ	26.57	63.43
Cone Distance, R	67.08 mm	
Facewidth, b	25	

From obtaining the overall bevel gear specifications, analysis on shaft can be done through several calculations to obtain minimum diameter shaft so that the shaft will not fail when load is applied. The formula obtained by using DE-Goodman Criterion formula as in Eq.4 below

$$\mathrm{d} = \left(\frac{16\mathrm{n}}{\pi}\left\{\frac{1}{\mathrm{S_e}}\left[4(\mathrm{K_f M_a})^2\right]^{1/2} + \frac{1}{\mathrm{S_{ut}}}\left[3\left(\mathrm{K_{fs} T_{req}}\right)^2\right]^{1/2}\right\}\right)^{1/3} \qquad Eq.4$$

The shaft diameter required on pinion is 16.13 mm while the shaft diameter required for gear is 41.85mm.

3.3 Simulation

Solidworks 2020 simulation is crucial step in determining either the product will fail or not when undergoes certain amount of forces or load. Only 3 crucial parts are going through simulation which is body frame, rigger blade and blade shaft. By doing simulation it can find the maximum and minimum spot that the stress or strain occur so that the design can be modified on the critical part or point. Furthermore, simulation can give a value on Von Mises stress, strain value, displacement value and factor of safety. Table 3 indicates the simulation result on the crucial parts.

Table 3: Simulation result

Parts	Max Von Mises Stress (MPa)	Max Strain	Max Displacement (mm)	Min Factor of Safety
Body Frame	3.062	$5.355e^{-4}$	6.170	1.997
Rigger Blade	18.000	$4.190e^{-5}$	0.050	$2.945e^{1}$
Gear Shaft	19.28	$2.000e^{-4}$	0.100	3.933

The maximum Von Mises stress occurs at the gear shaft while the maximum displacement is at body frame with value of 6.17mm. Plus, the safest parts is rigger blade because it has a bigger value of factor of safety while the highest elongation or strain occurs at body frame.

3.4 Final design

After a lot of revise on drawing made to double digging machine and by taking a lot of factors such as cost, maintainability, mobility and user friendly, Double Digging Machine design has been finalized. Figure 3 is the final product to be fabricated later.

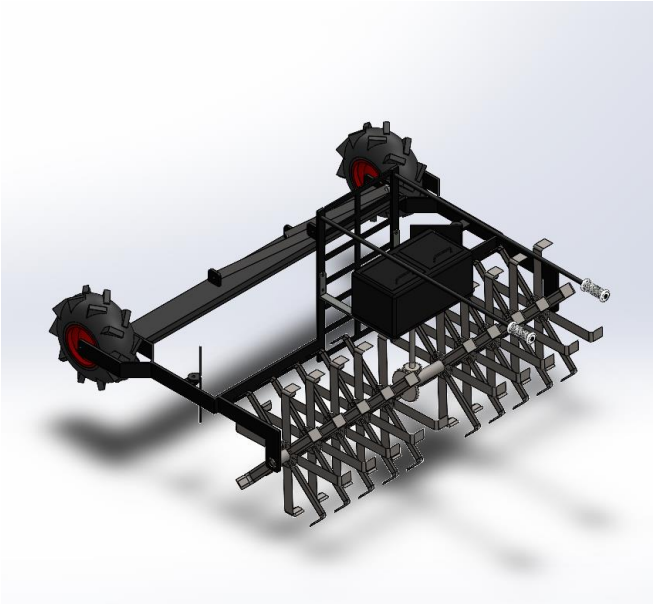

Figure 3: Final Design of Double Digging Machine

4. Conclusion

In conclusion, Design 2 was selected and improvised to obtain the best ideas and outcome in designing Double Digging Machine. Plus, the drawing done by using Solidworks 2020 software is one to one with the real product when fabricated later. The machine can be said that it is safe to be used as in simulation result that the product will not fail during operating on soil. Moreover, it can be concluding that the machine will help the small farmers and gardeners cut their time to prepare the soil by using Double Digging technique and machine designed.

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