Scrambler Machine

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Abstract:- The majority of farmers in tropical parts of the world cultivate areca nut as a commercial crop, India being a major producer of this crop with an annual yield of 3.6 lakh tonnes. The current market value for areca nut is 52000 INR per quintal making it a lucrative crop to cultivate. Mechanization of this job is very much required. This reduces occupational hazards and dependency on labourers. In this paper, we present the design of an engine-powered semi-automatic machine to climb areca trees thus eliminating manual climbing for harvesting and spraying purposes. Stability analysis gives the key parameters for the design of the chassis. Using the parameters, virtual simulation to validate the model and realization of the model through fabrication and testing. This machine is useful for climbing trees at a faster rate, less moving parts, use of self-weight for stability, portability, retrofit model are some of the advantages of this design.

Keywords:- *Areca Tree, Climbing Robots, Labour Scarcity, and Mechanization, Rolling Self-Locking, Stability Analysis.*

I. NOMENCLATURE

D = Tree Diameter; m = Mass of vehicle(Kg); Fs = spring force(N) ;W= Weight(N); F_t = tangential force on wheels ; F_{n1} = F_{n2} = Normal force on wheels(N) ; F_3 = Force on 3[rd] wheel(N) ;μ_k = Kinetic Friction(N) ; r_w = Wheel radius(mm). P = Power; S_{ut} = Ultimate tensile strength; M_t = Torque transmitted ; τ = shear strength; G = Rigidity Modulus; θ_1 = angle of twist in radians.

II. INTRODUCTION

Areca nut is a commercial, lucrative crop to cultivate. It grows well in tropical high rainfall areas. Many farmers' incomes depend only on this plantation throughout the year. Over six million people in India are engaged in cultivating, processing and trade. Being one of the most lucrative crop to cultivate increasing the number of individuals in the supply chain of framing and trading of this crop. Hence the farmer is not at advantage position to substitute harvests even during turbulent periods because of the resource particularity of his yield. Pesticide spraying, Harvesting, Drying, De-shelling the nuts are the major processes of this trade. The farmer has to climb a 40-meter-tall slender tree and perform spraying and harvesting activities. Unintendedly many farmers put many tree climbers in jeopardy this could imperil their livelihood. There is a strong leap of faith while climbing trees which may turn into leap in the dark because a potential diseased tree can dismember and brake. Thus tree climbing is itself a part of professional activity in this trade requiring a particular skill set to execute it. A study shows that many accidental falls occur with old and experienced climbers. This is because of reduction in functional efficiency of arch adapting ligaments [3]. Most of them end up with bruised hands, deformed feet, or at least swelled up hands and feet.

The high skilled tree climbers are reducing and the new generation labourers are not motivated to pick up this professional skill as most move to cities to find better living. This creates huge demand for tree climbers and their availability during peak seasons becomes more challenging. Hence small scale farmers have to spend more than one third of their revenue in these two processes. This manual method of climbing has to be mechanized as there is resistance in continuing this profession by the younger generations due to which labour scarcity is increasing. Most tree climbers do not take any safety precautions while climbing the tree. One side the increasing number of farmers taking up areca nut cultivation and on the other side reduction in skilled tree climbers have widened the gap, thus creating an opportunity for mechanization of tree climbing process.

Integration of man and machine makes the process less labour intensive. Machine which replaces the manual tree climbing ensures safety and reduce expenditure, drudgery of farmers. It increases in the timeliness of operation and rate of production and therefore profitability. An ideal areca tree climbing machine should be simple to operate, effortlessly climb trees and return , portable, no slipping during rainy seasons, should not damage tree surface, using less energy to operate, large scale operation, least idle time an least cost to manufacture.

III. RELATED WORK

This literature survey includes various designs which have been successful in fabrication and testing their proof of concept. Tree climbing machine has been under investigation for last 2 decades. Different methods have been adopted for this purpose. They can be broadly classified as continues and discrete type of climbing. Renganathan (2012) has developed a manual tree climbing equipment called *Multi tree climber [8]* which adopts discrete climbing technique. Provisions are made for sitting and holding purposes. It has 2 frames controlled by body weight and feet. An adjustable locking pin makes this equipment a flexible one applicable on trees with various diameters. Major disadvantage which demotivates farmers from buying this equipment is that during hands free position conscious effort should be made by the person to apply a counter balance force on upper and lower frames to prevent slipping and instability. As a safety precaution a harness belt is used.

Ganapathi Bhat (2019) has developed a motorized vehicle that can carry humans on top of tree. The *Tree scooter [5]* uses a 2 stroke ohv petrol engines as prime mover. A clutch reducer gearbox, sprockets and 2 chain drives are used as power transmission to control front and top wheels which rotate in opposite directions. It uses drum brakes to minimize the input force. For safety additional brake unit and harness belt are used. The machine has two tyres and a roller that interlocks to grasp the tree's smooth trunk. This is a scooter machine capable of caring human with max load of 80 kgs. Major concern is that during spraying and harvesting seasons the tree surface would be soft and slippery because of constant exposure to high moisture and humidity. If the machine fails by slip human life would be at stake. In case the brake fails, a backup brake will jam the wheels and stop the vehicle from rolling down the tree. Another concern is that if that tree diameter is less than 3.5 inches then it would add huge strain on tree and also may shear the tree which is a dangerous to lives of humans.

Prakasan (2013) fabricated a manual tree climber machine called *Wonder Climber [7]* which uses a rope, pulley mechanism to operate and it or is safer compared to other climbing techniques. lt is again a discrete motion as there is expansion and contraction using pulley and spring mechanism. Considering the vastness of areca plantation this machine is very slow in climbing, harvesting and detaching.

Autonomous tree climber robot [9] is a low cost prototype which uses discrete climbing technique. This work includes DH conversion for manipulators, mechanical design, motor selection, locomotion algorithm development and fabrication. Power screws are used for actuation while ascending and descending. A robotic manipulator with a rotary blade as end effector is used for harvesting purpose. The robot is autonomous but can be remotely overridden. The locking mechanism happens from detecting the surge in current and the control action is implemented to prevent further tightening. To detect extreme points of vertical motion IR sensors are used the prototype is in its initial stages and needs further work to make it efficient.

Pole climbing robot UT-PCR [2] was designed and fabricated by A.Sadeghi et al (2011). It is a continuous type of climbing robot using a natural compensation for stability. This is simple design with less moving parts inspired by primate climbing technique. The increased payload enhances traction. it is shown that beyond threshold frictional force stability is independent of weight factor. The robot is driven by motors and uses a v shaped wheels to increase the area of contact and also to constrain the direction of motion. This robot is successfully tested in 2 sizes. It is used for electric pole climbing and cleaning the street lights.

Pneumatic tree climber [12] uses compressed air to climb trees. The harvesting mechanism is through the shearing effect of the pruning blade which uses compressed air to actuate. It is designed such that the upper body extends and grips the tree, then the lower body retracts to its original position. A spraying unit is attached to the lower part of the machine and the harvesting module can be attached to the upper part of the machine. The compressor is required to maintain air pressure, but this model is not effective because of the scale of the field and terrain of the land, it would be difficult to carry a compressor around the farm. Bekal (2017) has designed and fabricated.

Tree climber machine [14] which works on the basic principle of friction with a X frame and two rollers at the bottom. The conically shaped rollers provide wedge action between the tree surfaces, maintain a strong contact. It also consists of a movable arm which can rotate at a 360 degree angle and is used for spraying pesticides. It is connected to a Battery whose wires are passed all the way down the tree to the ground. The machine is controlled based on human judgment and also the system is only restricted up to the spraying of pesticides hence these drawbacks limit the use of this machine at a certain height up to a visible range.

An *autonomous robot [17]* built by Devang et al.2010. is capable of climbing and pruning areca trees. It is a non-linear self-regulating system with flexible structure. This continuous motion system is powered by two motors with 30 kg-cm torque capacity. It uses a self-stabilizing climbing technique. There are 2 active and passive wheels to achieve this objective. The robot structure is made of PMMA material making it light weight A PUMA arm with 5 DOF is mounted on robot and is used for harvesting purpose. Digital image processing and object recognition is used as intelligence. The microcontroller is arm cortex with Da Vinci processor. A manual override is provided in case of automation failure.

IV. METHODOLOGY

The semi-automated tree climber is designed to climb the areca nut tree and harvest it. In this paper we present the stability analysis, design and testing of areca tree climbing machine.

The stability is important criteria for designing this machine. The center of gravity is away from tree creating an anti-clock wise moment around tree creating a compressive force which increases the grip, thus enabling traction. When the strut forces were less, due less traction it was slipping. Getting a perfect balance point between these parameters was the key to stability and smooth climbing. Climbing based on Rolling self-locking phenomena that locking happens by only friction forces only [1]. The condition must satisfy such that the frictional forces must be greater than the vertical component of the weight and in accordance, the geometry must be designed.

UT-PCRII was designed with a special characteristic: the heavier the payload, the better the stability of the robot. The self-weight of the robot creates high frictional forces to enhance traction and acts as a natural compensation for enhanced payload [2].

Keeping the above theory in consideration, the Geometry will be designed. The angles and range of travel of the 3rd leg design will be found in Solid Works Software. The analysis will be performed in ANSYS software. Then the model is fabricated and experimentally verified for the stability and functionality of the machine.

Here we provide the analytical calculations and geometric proportions required for the same. The design involves formation of a mathematical and geometrical model followed by CAD and FEA procedures.

a) Tree Dimensions

The machine should climb the tree with having diameter range from5.5 inches to 2.75 inches. The tree length is around 30,000 mm, with a slope percentage of 0.116. The harvesting season is rainy and winter, so tree surface are considered to be wet wood.

b) Stability analysis

The prototype is initially analysed for determinations of reacting forces and moments on the body so that it can be designed and optimized .It is reduced to simple model where the static forces are dominant and by static analysis the forces are known.

Assumptions

- Vehicle moves slowly so that static forces are
- dominant.

  Self-Weight of frame, transmission and other components are not considered.
- Center of mass lies on the same plane of the x axis.
- Effect of spring is not considered as it only increases the stability.
- Radius of wheels is negligible.

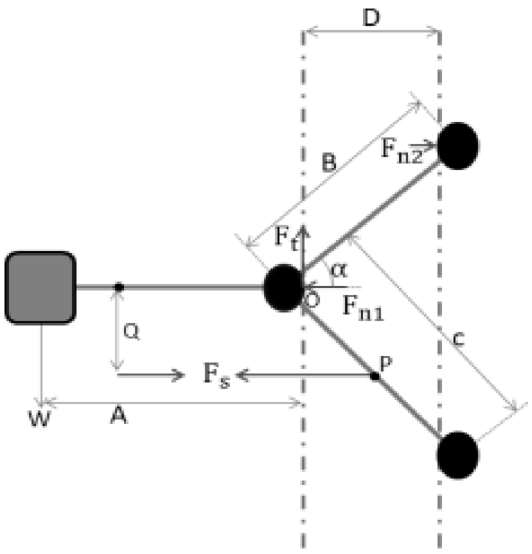

Fig.1. schematic of the machine

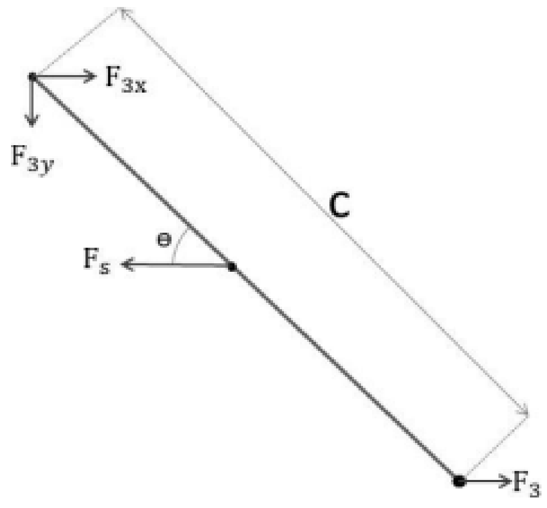

Fig.2. FBD of 3rd leg

Static analysis to determine the length of center of mass from the wheel.

From figure 1.0

$$\sum F_x = 0$$

$$F_3 + F_{3x} - F_s = 0 \quad (1)$$

$$\sum F_y = 0$$

$$F_{3y} = 0$$

$$\sum M = 0$$

$$F_3 x C \sin\theta - F_s x OP \sin\theta = 0 \quad (2)$$

$$F_{3x} = F_s - F_3$$

$$F_3 = \frac{F_s x OP \sin\theta}{C \sin\theta}$$

$$F_3 = \frac{F_s x OP}{C} \quad (3)$$

From Fig.2

$$\sum F_x = 0$$

$$F_{n1} = F_{3x} + F_{n2}$$

$$F_{n1} = F_s x \left(1 - \frac{OP}{C}\right) + F_{n2} \quad (4)$$

$$\sum F_y = 0$$

$$F_t - F_{3y} - W = 0$$

$$F_t = W = mg$$

$$\sum M = 0$$

$$-F_{n2} x B \sin\alpha + F_s x P + W x A = 0 \quad (5)$$

$$\mu_k = -\frac{F_t}{F_{n1}} = \frac{F_t}{F_{n2}} \quad (6)$$

$$F_{n2} = \frac{mg}{\mu_k} = -F_{n1}$$

substitute in eqn.4 we have,

$$F_{n2} = -\frac{W}{\mu_k} - F_{3x}$$

$$F_{n2} = -\frac{W}{\mu_k} - F_s x\left(1-\frac{OP}{C}\right)$$

$$F_{n2} + F_s x\left(1-\frac{OP}{C}\right) = -\frac{W}{\mu_k}$$

$$\mu_k = -\frac{W}{F_{n1}+F_S\left(1-\frac{OP}{C}\right)} \quad (8)$$

When $F_s = 0$ we have,

$$\mu_k = \frac{W}{F_{n2}}$$

$$F_{n2} = \frac{W}{B\sin\alpha}$$

Conditions for μ_k to avoid slip,

$$\frac{B\sin\alpha}{A} \le \mu_k \quad (9)$$

This design shows that the center of gravity of machine is far from the tree along the axial length of the wheel due to which stability is achieved along with the variable diameter of tree.

Another advantage is that as the payload increases the system would stabilize better but is limited to the strength of the tree and engine capacity. Using gas struts of appropriate forces we can avoid the increase in redundant mass to stabilize the machine.

This design also shows that since the balancing action has negligible effect in the z direction, the machine can be easily removed from tree. This saves idle loading and unloading time and increases convenience.

From eq.9 we have

$$\frac{B\sin\alpha}{\mu_k} \le A$$

Tree Diameter $D = B\cos\alpha$

As the tree diameter reduces we need higher frictional forces to stabilize, when payload is away from tree the required frictional forces reduce.

Rate of climb

Length of tree L = 30 mts

Number of revolutions N = $\frac{L}{2\pi r}$

N ranges from 86 rpm to 140 rpm.

Wheel diameter ranges from 2.7 in. to 4.34in.

c) Vehicle Dimensions

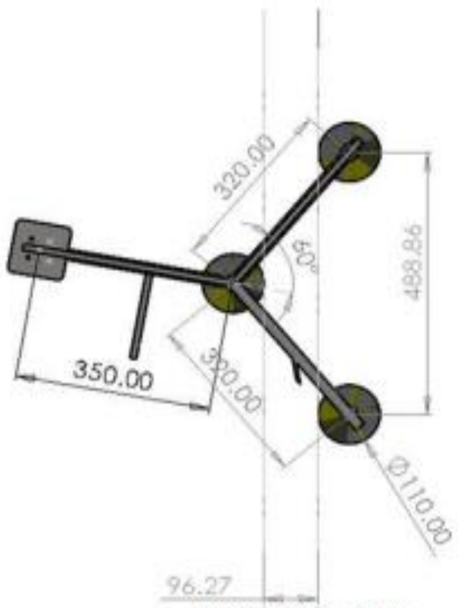

Fig.3. Vehicle Proportions

Power required-

For torque required by wheels we consider the reactions from above calculation .The figure 3.3 has been modeled and simulated using the same analytical data.

m= 10 kg; W = 98.1 N;

$WxA = 34335\ N\text{-}mm$

$$F_{n1} = \frac{WxA}{B\sin\alpha}$$

$$\Rightarrow \frac{34335}{320\sin 60^\circ}$$

$\Rightarrow 123.895\ N$

$F_{n2} = F_3$

$\Rightarrow 63\ N$

$$F_s = \frac{F_3 xC}{P}$$

$\Rightarrow$ 124 N

$$\mu_k = \frac{B\sin\alpha}{A}$$

$\Rightarrow$ 0.79

taking $\mu_k = 0.85$

$F_t = \mu_k x F_{n1}$

$\Rightarrow 5.79\ N-m$

Taking the gas strut effect into consideration we get the following equations,

$f_a = 350\ N$; $w = 4$ kg; a = 355 mm;

$b = 330\ mm$; $\alpha = 60$;

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$$(wxa) + \left(f_d x \frac{b}{2} x\cos\alpha \right) = 0$$

$$F_{s1} = \frac{(wxa) + \left(f_d x \frac{b}{2} x\cos\alpha \right)}{b\sin\alpha} = 149.7\ N$$

$F_t = \mu_k x F_{s1}$

$\Rightarrow 119\ N$

$T = F_t x R_{wheel}$

$\Rightarrow 6.5 N - m$

$n_1 = 5000\ rpm;\ z_1 = 9;\ z_2 = 80;\ \eta = 0.95;$

$$\frac{n_1}{n_2} = \frac{z_2}{z_1}$$

$i = 8.88;\ n_2 = 563\ rpm;$

$$Power\ (k.W) = \frac{2\pi NT}{60000}$$

$$P = \frac{2x\pi x563x6.5}{60000}$$

$\Rightarrow\ 0.383\ k.W$

Design of shaft subjected to torque-

Since the length of shaft is not long bending effects are not considered.

Part name – Shaft 1

Material – C40

$S_{yt} = 380\ M.pa$

$F.O.S = 3$

$$\tau = \frac{0.5xS_{yt}}{3}$$

$\Rightarrow 63.33\ M.pa$

$$M_t = \frac{9550x1000xN}{n}$$

$\Rightarrow 71825\ N - mm$

$$D = \left\{ \frac{16}{\pi x\tau} xk_t xM_t \right\}^{\frac{1}{3}}$$

$\Rightarrow 17.94 \approx 18\ mm$

Diameter of the shaft is 18mm

$$D = \left\{ \frac{584xM_t xl}{Gx\theta_1} \right\}^{\frac{1}{4}}\ [10]$$

$G = 78x10^3\ M.pa$

$L = 3.3795xD$

$\theta_1 = 0.3^{\circ}$

$\therefore$ Design is safe

Torque capacity of the brake -

Velocity = 15 k.m.p.h

Wheel diameter = 0.110 m

Angular velocity

$$\omega = \frac{v}{r}$$

$\Rightarrow 75.745\ rad / \sec^2$

Moment of inertia of wheel

$I_1 = 0.00128\ kgm^2$

Mass of wheel = 0.814 kg

Material is SS-316

Kinetic energy of wheel

$$K_{e1} = \frac{I_1 \omega^2}{2}$$

For 3 wheels $3xK_{e1}$

$$\Rightarrow \frac{3}{2} x0.00128x75.74^2$$

$\Rightarrow 11.015\ J$

Kinetic energy of the vehicle

$$Ke_2 = \frac{1}{2} x (mv_1 - mv_2)^2$$

$$\Rightarrow \frac{1}{2} x20x\left(4.166^2 - 0\right)$$

$\Rightarrow 173.5\ J$

Total Kinetic energy $K = K_{e1} + K_{e2}$

$\Rightarrow 184.515\ J$

Energy absorbed by the brakes $E = \frac{K}{2}$

$\Rightarrow 92.25\ J$

Deceleration

$d = \mu g$

$\Rightarrow 0.3x9.81$ m/s^2

Brake time

$$t = \frac{v_1 - v_2}{d}$$

$\Rightarrow t = 1.14\ s$

Average velocity

$$v = \frac{\omega_1 + \omega_2}{2};\ \omega_2 = 0;$$

$$\theta = \frac{\omega_1 t}{2}$$

$$\Rightarrow \frac{75.74x1.14}{2}$$

$\Rightarrow 43.17\ rad$

Torque capacity of brake

$$M_t = \frac{K}{\theta}$$

$\Rightarrow 2.13\ N - m$

d) Wheel geometry validation-

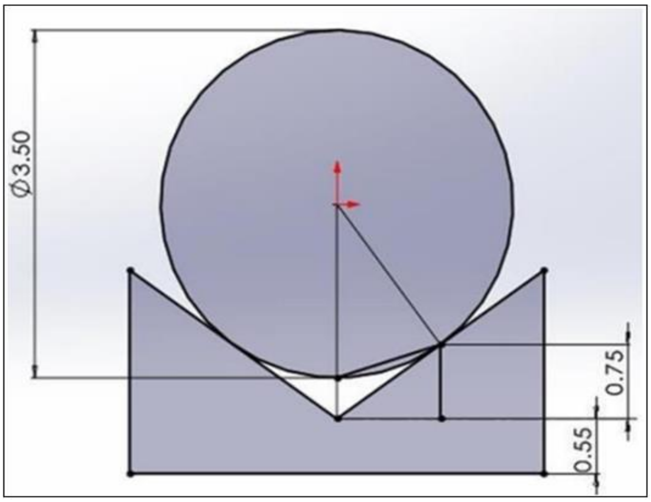

Fig 4 Wheel A (at 3.5'' dia. tree)

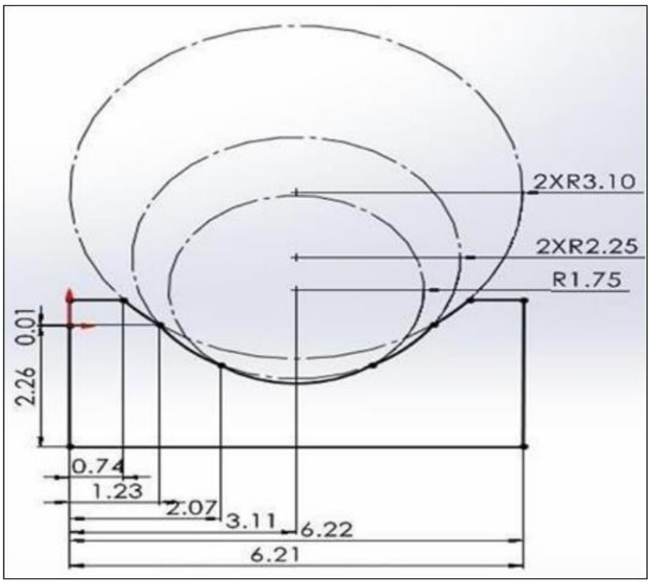

Fig 5 Wheel C (Accommodating for all tree diameters)

➢ *2-D Model-*

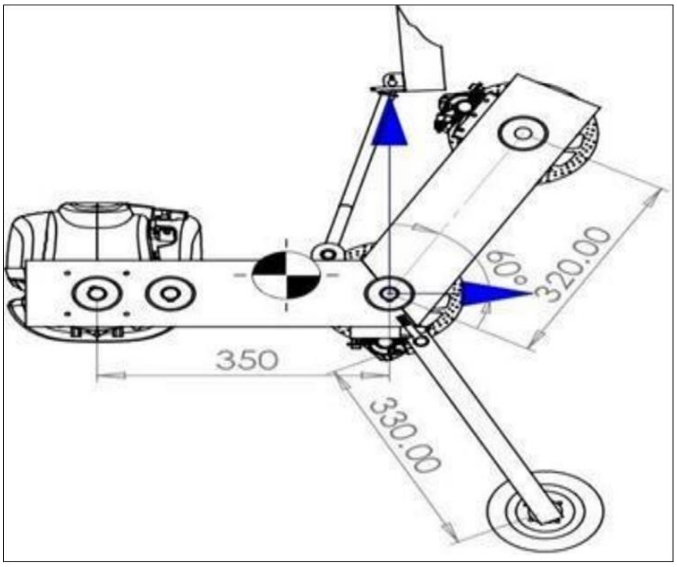

Fig 6 Front View

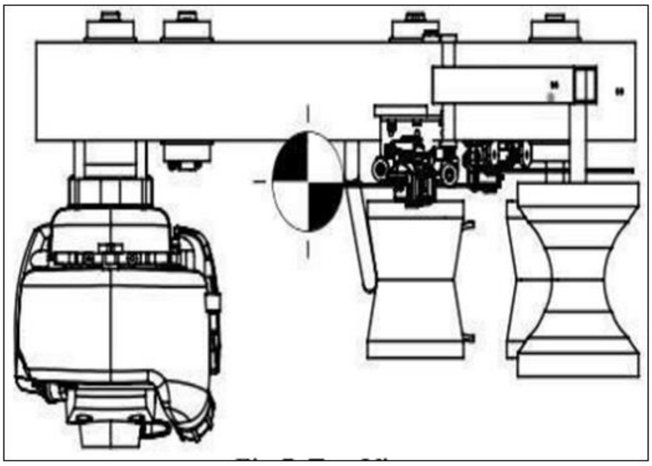

Fig 7 Top View

➢ *3-D Model*

Fig 8 Isometric View

V. SIMULATION AND RESULTS

The simulation solver solves the governing physics in time bound manner. Static and dynamic frictional coefficient of 0.75 and 0.8 respectively are used to simulate 3d contact. Engine and gas strut forces are applied respectively on the ends of the frame. Using the motion analysis tool dynamic analysis was performed to visualize the system in action as shown in fig 9.

Multibody dynamics software Msc Adams solver was used which is integrated into solid-works as motion analysis toolbox which performs Multibody dynamics simulations. From the theoretical calculations slip is one factor which has to be minimized as the machine has to perform with minimum slip condition. Hence the objective is to determine the minimum coefficient of friction for stability and no slip condition the forces required by the gas struts to provide enough force for grip. This helps to study the power consumption, torque required, reaction force, frictional forces, time taken to complete the task from which slipping can be avoided.

➢ *Parameters Involved for Motion Analysis are as follows,*

- Integrator type GSTIFF
- Iterations 50
- Initial integration step 1e -4
- Min integral step size 1e-7
- Max integral slip1e-2
- Jacobean entry
- 3d cad data resolution
- Static friction of 0.9
- Dynamic friction of 0.8

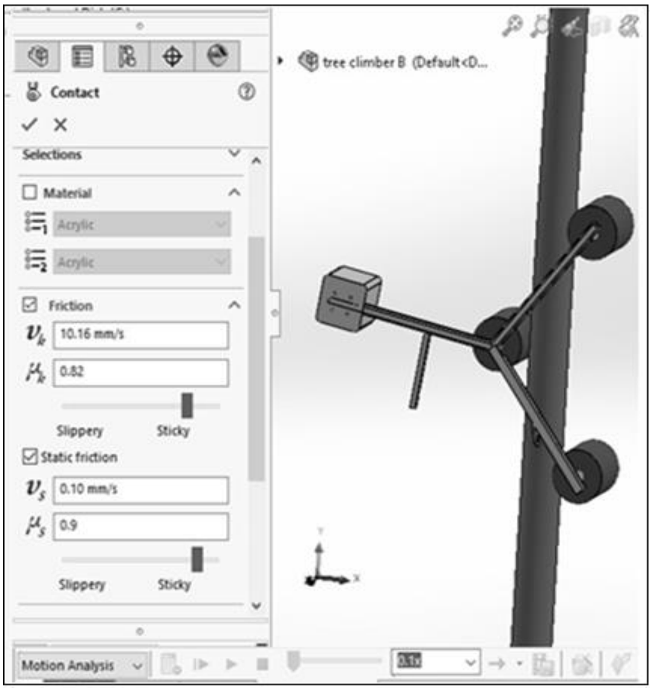

Fig 9 Simulation

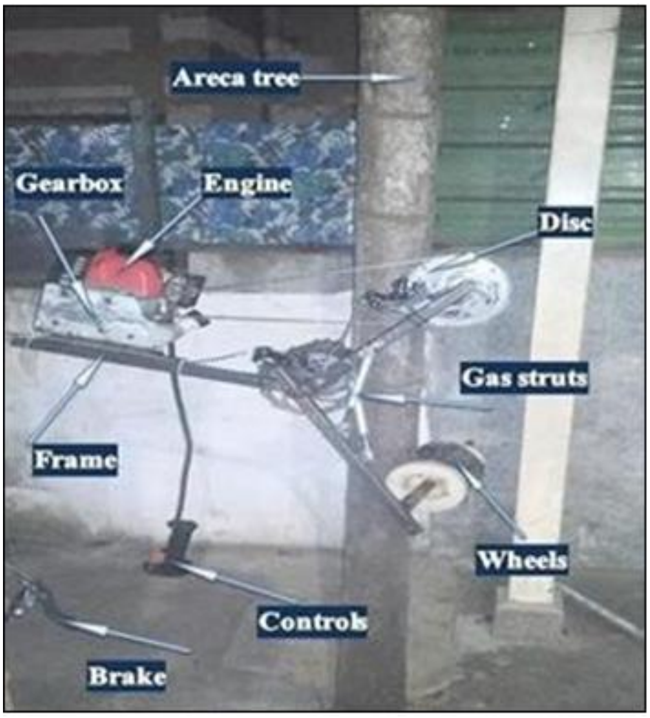

Fig 10 Static Test on Tree

➢ *Simulation Results*

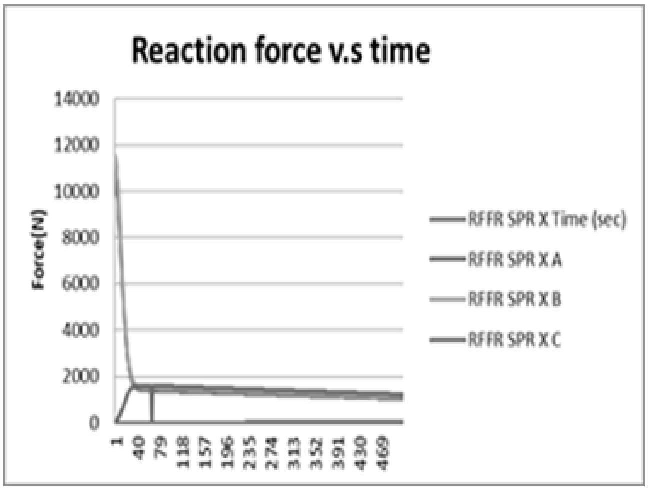

Fig 11 Reaction Force Plots

Figure 11shows the reaction forces of the wheels a,b,c with resprect to time.The decrement in reaction force with resepct to time is proportional to the reduction in tree diameter with altitude. The thin cross section of the tree at the top reacts lesser that the bottom portion of the tree hence more force is required to stablize the machine at the top as shown in fig 10.

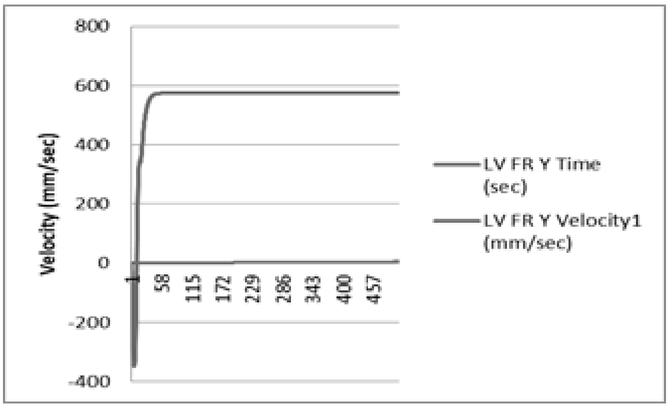

Fig.12. Velocity v.s time

From Figure 12, we see that the climbing rate is 570 mm/sec and the model attained the height of 3842mm in 5 seconds resulting in the climbing rate of 5670mm/sec.

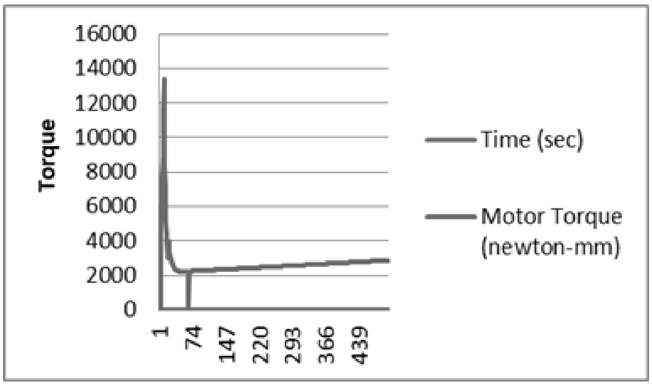

Fig 13 Torque Plot

While experimenting we noted that slip occurs when friction are below 0.6 but stable at.7 gradually increasing traction. The analytical model and results from simulation helped to get design insights for fabrication to reduce iterative design cost.

Figure 13 shows that torque increases with reduction in diameter as the machine ascends the tree. These plots give significant design insight on position quantity of peak power requirements for fabrication.

- *FEA Results*

Finite element analysis is performed to inspect the stress levels, deformations in the model. From fig 14, 15 we see the static structural analysis using ansys software v3 version to determine von mises stress and total deformation. Forces from body weight, engine inertia, gas struts, and wheels were considered. The material used is structural steel. The frame was meshed with medium smooth quality with 14598 nodes and 6939 elements. Maximum von mises stress of 34 Mpa and deformation of 0.29 mm. Here the frame performed well with safe stress levels and negligible displacements.

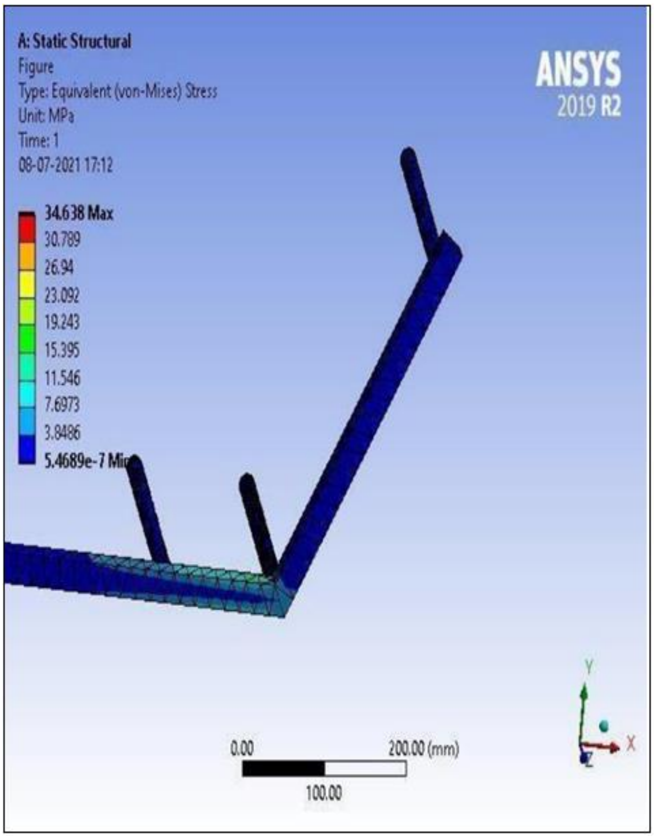

Fig.14. Von- Mises stress

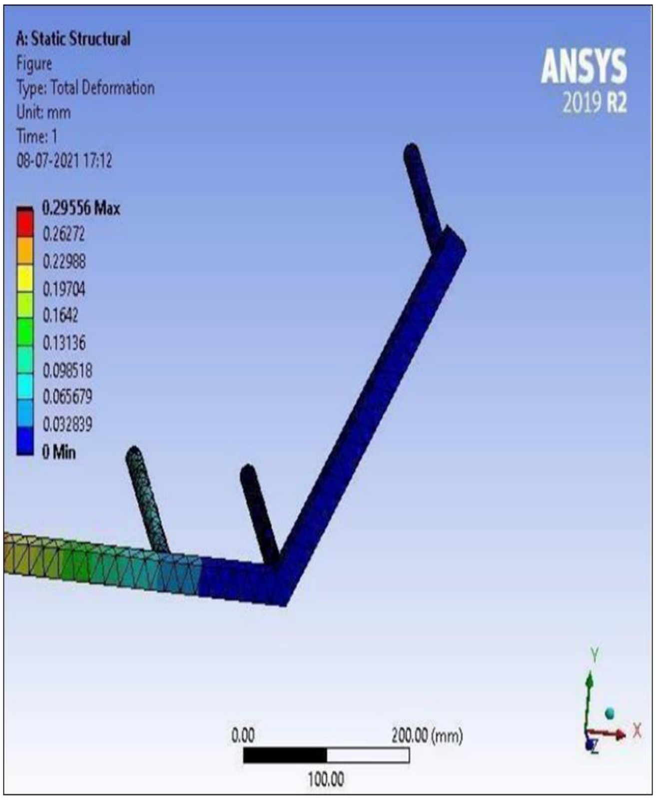

Fig 15 Total Deformation

VI. CONCLUSION AND FUTURE WORK

Labour scarcity has emerged foremost challenge as the demand during the peak harvesting, spraying seasons are rising. Mechanization of this job reduces the expenditure of farmers and most importantly reducing occupational hazards.This project involves design, analysis, and fabrication of a semi- automated tree climber machine. It has been tested for working conditions, the machine climbs the tree thus reducing labour dependency to achieve this task and thus reducing the occupation hazards.Center of mass is placed significantly away to stabilize the machine.

Using FEA, MBD, structural, dynamic evaluation was done using Solid Works and Ansys softwares. Motion analysis was done on virtual model to check stability in static and dynamic conditions. Easy removal from tree which saves time and reducing effort, lightweight design make it easy to carry around the farm. This machine is a base machine for which provisions for attachments like pesticide spraying and areca tree harvester can be designed and fabricated. It is currently in semi-automatic stage but can be further developed to become a fully-fledged automated system with sensors and actuators.

The machine can be further optimized by increasing the maximum efficiency by altering the bent angles of frame the distance of the center of mass, wheel geometry. Wheel force transducers can be used to determine the forces on the tree that cause the tree to break. This can be achieved by the application of Kill switch with sensor sensing the brake point of tree.

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