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Design and development of a tractor mounted hydraulic operated ladder

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■ **ABSTRACT :** A tractor-mounted hydraulic operated ladder was designed and developed to reduce the harvesting /pruning cost, increase the harvesting/pruning efficiency and enhance the overall productivity of mango orchards. The design and drawing of hydraulic ladder was made and theoretical analysis of the tractor mounted hydraulic operated ladder was carried out by finite element method, using solid works software for finding the stress and stability of the hydraulic ladder and stress under static load for the hydraulic ladder. It was observed that the variations in the resultant forces are minimum for different heights (6, 8 10m), different angle of rotation from 0-180° at an interval of 45 and different varying loads 75, 150, 225 and 300 kg, respectively. It is considered to be in a state of stability when no sign of overturning is evident with the hydraulic ladder in operation. The maximum stress observed in the hydraulic ladder for, 8m and 10 m height with different loads and different angle of rotation is 96.64 N/mm^2 which is less than the yielding stress which is 220.59 N/mm^2. The developed system is attached to the rear of a minimum 45 hp agricultural tractor. System's power source is the tractor hydraulic system. The hydraulic ladder has the capability to lift a service worker and the required tools to the crown zone as high as 10 meters. The hydraulic ladder consists of a stabilizing system (four cylinders) on both side of the trailer for supporting, stability and safety for the operators at the time of operation.

■ **KEY WORDS :** Hydraulic ladder, Design, Stability, Tractor mounted, Stress, Stabilizing system

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Harvesting of fruits is a labour-intensive operation worldwide, which accounts in many cases for about 50 per cent of total production costs. In India, fruit harvesting is commonly done by experienced tree climbers. Fruit harvesting is a tedious, stoop type job, which is needed to be performed on a seasonal basis during a relatively short time. Besides, issues of safety and quality of plucked fruits during manual plucking are the matters of concern. The declining labour availability and increasing labour costs in the developing countries, combined with more awareness to health and safety issues, make it mandatory to mechanize the fruit harvesting operation. Fruit growers in the developing countries are facing two significant problems that could determine the future of their business. The availability of fruit harvesting labour dwindling every year and the supply of hand fruit pickers continues to shrink. In addition, there are fewer workers available to harvest fruits because of continuous outflow of workers from agriculture to better paying jobs in construction and industry (Blank, 1998). Since the cost of manual labour is constantly rising, the only way to maintain or reduce the labour cost is to increase the productivity of lab markets (Holt, 1999).

With day to day increasing labour charges and migration of the rural people to urban areas, it has become mandatory to manage all horticultural operations mechanically. Therefore, development of machines is a timely step to reduce the drudgery and to increase the yield potential of horticultural crops (Tajuddin *et al.*, 2002). Mechanized harvesting can facilitate the harvesting and packing work, labour- saving machines (mass-harvesting systems) that improve productivity and reduce harvest and packing labour needs and robotic harvesting or automation. Several works have been carried out to develop suitable labour-aids, primarily for fresh-market fruit. Different models of various mechanical picking aids have been developed in many places in the world over a period of more than 50years. They cover the whole spectrum of labour aids from improvements in clipping devices, ladders, picking bags and working methods to a variety of picker positioning equipment from simple multi-man platforms to a real sophisticated single-man, self-propelled positioning system (Coppock and Jutras, 1959; Perry, 1965; Molitorisz and Perry, 1966; Seamount, 1969; Berlage *et al.,* 1972; Sarig and Coppock,1986 and Sarig, 1993).

Fadal (2005) conducted a study on development of a tractor-mounted date palm tree service machine. Two outriggers support the base and other system components to avoid excessive tire pressure while machine is in operation. The base carries a rotating joint in its middle, where a horizontal hydraulic cylinder is used to swing the joint and the elevator-platform assembly accordingly. Two control panels are installed to control the machine. One of them is located on the base unit, where it may be used from the ground and the other one is located on the platform to be used by the operator on top. The ground controller controls the out riggers, raising, lowering or swinging the platform. On the other hand, the second control panel, which is placed in the platform where the controller has the ability to control the whole system, including the winch located on the platform.

Shanab and Sepehri (2005) describes the development of a simulation model for studying the tip-over stability of a typical heavy-duty hydraulic log-loader machine. The results demonstrates that the effects of the manipulator movements, the flexibility of the contact between the base and the ground, the hydraulic compliance and the friction properties between the wheels and the ground, on the stability of the machine. Particularly, it is shown that the flexibility of the contact between the base and the ground reduces the machine stability, whereas the flexibility at the manipulator joints due the hydraulic compliance improves the machine stability.

Mira *et al.* (2008) conducted studies on design, construction and testing of an apricot tractor trailed harvester. In this harvester the two articulated arms at the rear of the chassis and the wheels are attached at the end of these. These arms move independently on a vertical plane, each of them motioned by a hydraulic cylinder. This movement, combined with the tractor’s elevator system, allows for the harvester’s levelling in the longitudinal and transverse directions. The trailer’s maximum height over the ground is between 0.2 and 1.22 m. This higher clearance allows the unloading of apricots into the boxes or box pallets with a minimum dropping height, preventing fruit damage. The arm-wheel hydraulic cylinders are operated by the tractor’s external oil system. Hydraulic controls are located on the left rear side of the trailer. A person walking next to the harvester with a manual branch shaker could also control the trailer hydraulics.

Kolhe (2010) designed the tractor mounted hydraulic lifter for harvesting, pruning and spraying of horticultural fruit trees. The study of various control systems such as pneumatic, hydraulic, hydro-pneumatic and electrical control reveals that the use of hydraulic control system will be more beneficial and reliable for the current development. The tractor mounted hydraulic lifter for fruit harvesting, pruning and spraying was developed by integration of agricultural and mechanical engineering concepts, manufacturing processes, material properties and tree characteristics. The principles of hydraulics circuit were used and accordingly turn table, harvesting arm, harvesting bucket and tractor mounting assembly was designed and developed.

Kolhe *et al.* (2011) model analysis was carried out for the whole assembly of tractor mounted hydraulic elevator by using Ansis software. The better stability results with the controlled vibrations and frequency of the lifting platform and welded joints were recorded by keeping constrained boundary conditions. The tractor mounted hydraulic elevator is suitable, safe, less hazardous and economical as compared to manual climbing for coconut harvesting. Hence, it is recommended to use tractor mounted hydraulic elevator for harvesting, cleaning and breeding of coconut orchards upto 14 m height.

Abhinay and Rao (2014) modelled an aerial scissor lift by using ANSYS software which is one of the software used for modeling components in most of the design based industries. While the modeling of the components the material selection is carried out simultaneously based on the design considerations related to loads, etc. Later the stress and strain concentration, deformation on the aerial scissor lift have been found by applying certain load on the lift's platform, using the Finite Element Analysis (FEA) by using ANSYS software that provides best output within few seconds.

Jaydeep and Pandya (2013) described the design as well as analysis of a simple aerial scissor lift. Conventionally a scissor lift or jack is used for lifting a vehicle to change a tire, to gain access to go to the underside of the vehicle, to lift the body to appreciable height, and many other applications also such lifts can be used for various purposes like maintenance and many material handling operations. It can be of mechanical, pneumatic or hydraulic type. The design described in the paper is developed keeping in mind that the lift can be operated by mechanical means so that the overall cost of the scissor lift is reduced. Also such design can make the lift more compact and much suitable for medium scale work. Finally the analysis is also carried out in order to check the compatibility of the design values.

Henry *et al.* (2012) carried out the topology, size and shape optimization methods on a long range aerial lift truck. The first phase involves the determination of the optimum cross-section dimension, overlaps and wall thickness of the telescopic boom segments. The optimization problem is formulated as mass minimization under various structural performance constraints and solved using the metamodel-based optimization method. Optimal-space filling design, Kriging algorithm, and screening methods are used for the design of experiment (DOE) sampling, response surface generation and optimization steps, respectively. The second phase consists of 2 steps that deal with the search for optimum frame reinforcement layout using topology optimization in the first step and frame plate thickness optimization in the second step. The ultimate goal of design optimization in the second phase is to obtain a lightweight frame that is structurally stiff and with improved torsional natural frequency. The design optimization is done using ANSYS Workbench in the first phase while Hyper Works in the second phase. Optimized boom is about 250-kg (2.2%) lighter with significantly lower stresses than the reference design. The stiffness and torsional natural frequency of the frame increase by 33 per cent and 59 per cent, respectively with the weight reduce by 35-kg.

Kusuma *et al*. (2015) designed and fabricated a prototype telescopic raising platform for harvesting oil palm fresh fruit bunches. They have designed telescopic lifting mechanism, sliding mechanism and rope drive mechanisms to lift and take the platform near fresh fruit bunches at crown of the tree. The diameter and speeds of the first, second and third cylinders were 12.065 cm, 9.525 cm, 7.000 cm and 0.0779 m/s, 0.0421 m/s, 0.02624 m/s, respectively. The minimum deflection of the sliding mechanism was 2.81cm and rope drive needs 0.08hp to operate, which is less than the power availability.

In addition to providing means for reducing the drudgery of harvest labour the harvest machinery improves the farmers' ability to perform operations in time. Mechanization also reduces the risks associated with the need for large amount of seasonal manual labour for short periods of time and lessens the social problems caused due to excessive influx of low-wages. Keeping in view of above facts, the aim of this research work was to design and develop a tractor-mounted hydraulic operated ladder which should provide a safe working environment, in addition to presenting some important tools to help the worker performing the needed practice in a more efficient fashion.

■ METHODOLOGY

The drawing was made through solid works software and theoretical analysis of the tractor mounted hydraulic operated ladder was carried out by finite element method, using solid works software for finding the stress and stability of the hydraulic ladder.

Testing the stability of the hydraulic ladder:

Testing the stability of the hydraulic ladder was done by simulation method for finding the resultant forces acting on the four stabilizers L1, L2 and R1, R2. The simulation was done for the height of hydraulic ladder (two fold) from ground surface was kept constant at 6m. The load inside the bucket was kept 75 kg, for set of this condition different reaction forces on the stabilizer (L1, L2 and R1, R2) were taken by changing angle of rotation from 0-180° at an interval of 45° shown in Fig. A. For this set the load was varied from 75, 150, 225 and 300 kg, respectively. The same way for the other different heights, different loads and different angle of rotation was carried out by using the simulation module in the solid works software.

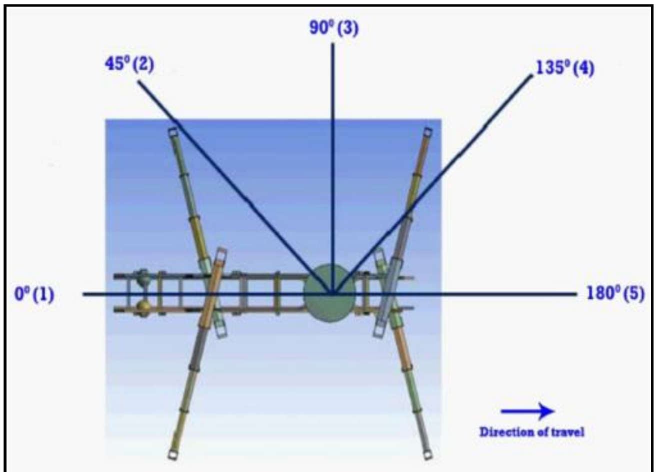


Fig. A : Angle of rotation from 0-180° at an interval of 45°

Von mises stress under static load for the hydraulic ladder:

The strength of machine members is based upon the mechanical properties of the materials used. Since these properties are usually determined from simple tension or compression tests. For ductile materials, the limiting strength is the stress at yield point as determined from simple tension test and it is, assumed to be equal in tension or compression. the failure or yielding occurs at a point in a member when the distortion strain energy (also called shear strain energy) per unit volume in a bi-axial stress system reaches the limiting distortion energy (*i.e*. distortion energy at yield point) per unit volume as determined from a simple tension test.

Design of tractor mounted hydraulic operated ladder:

Assume that hydraulic cylinder has to lift 500 kg that is 4905 N

To find the required hydraulic pressure

$$P = \frac{F}{A}$$

whereas,

F is the force, N

P is pressure, N/cm^2

A effective area of the cylinder, cm

$$A = \frac{\pi}{4} D^2$$

$$A = \frac{\pi}{4} 10^2$$

$$A = 78.5 \ cm^2$$

$$P = \frac{4905}{78.5}$$

$$P = 62.48 N/cm^2$$

The cylinder pressure is 62.48N/cm^2 :

Stroke length of a cylinder -90 cm

Oil capacity of the cylinder = Area x stroke length
= 78.5 cm^2 x 90 cm
= 7065 cm^3
= 7.065 litre/cylinder

To reach the operational height two hydraulic cylinders of same size are used for the two radial arms

=2 x7.065= 14.13 litre

Four hydraulic cylinders are used as stabilizers for supporting, stability and safety for the operators at the time of operation.

Assume that four hydraulic cylinder has to lift 1000 kg that is 9,810 N

To find the required hydraulic pressure

$$P = \frac{F}{A}$$

Whereas,

F is the force, N

P is pressure, N/cm^2

A effective area of the cylinder, cm

$$A = \frac{\pi}{4} D^2$$

$$A = \frac{\pi}{4} 6.3^2$$

$$A = 31.17 cm^2$$

$$P = \frac{9810}{4 \times 31.17}$$

$$P = 78.68 \ N/cm^2$$

The cylinder pressure is 78.68N/cm^2

Stroke length of a cylinder = 45 cm

Oil capacity of the cylinder = Area x stroke length

$= 31.17 \text{ cm}^2 \times 45 \text{ cm}$

$= 1402.7 \text{ cm}^3$

$= 1.4$ litre/cylinder

For four cylinder oil capacity is

= 4 X 1.4

=7.2 litre

Flow velocity:

Oil flow velocity in the line of hydraulic system is to be taken generally as 1 to 7m/s. Flow velocity of the oil depends on pressure side or suction side of pump, oil pipe construction, smoothness of surface, oil viscosity, oil pressure and pipe diameter.

The velocity of the cylinder for its forward and return motion is calculated by. Let us first convert the flow in LPM to m^3/s before calculating forward velocity

$Q_{in} = 45 \text{ LPM} = 45/(1000 \times 60)$

$= 1/1333.3 \text{ m}^3/\text{s}$

$= 0.00075 \text{ m}^3/\text{s}$

Now

D_C = Diameter of bore of the cylinder = 10 cm = 10×10^{-2} m

d_r = Diameter of piston rod = 50 cm = 5×10^{-2} m

$p = 0.6248 \text{ N/m}^2$ or Pa

– Forward velocity is given by :

$$V_{ext} = \frac{Q_{in}}{A_p}$$

$$= \frac{0.00075}{\pi d^2/4}$$

$$= \frac{0.00075}{\pi \times 0.1^2/4}$$

$$= \frac{0.00075}{0.00785}$$

$$= 0.0955 \text{ m/s}$$

– Return velocity is given by :

$$= \frac{Q_{in}}{A_p - A_r}$$

$$= \frac{0.00075}{\pi (d_c^2 - d_r^2)/4}$$

$$= \frac{0.00075}{\pi (0.1^2 - 0.05^2)/4}$$

$$= \frac{0.00075}{\pi (0.01 - 0.0025)/4}$$

$$= \frac{0.00075}{0.00588}$$

$$= 0.1275 \text{ m/s}$$

Construction of tractor mounted hydraulically operated ladder:

Proper design of functional components would greatly influence performance of hydraulically operated ladder. The design of functional components is made to achieve optimum performance of the tractor mounted hydraulically operated ladder. Based on the above design and requirement, prototype has been developed and discussed below. The functional components of tractor mounted hydraulically operated ladder are furnished below.

Trailer assembly:

It is a tractor drawn two wheel trailer developed with load bearing capacity and weight distribution by the considering the weight of the hydraulic ladder. The drawbar of the trailer height is 0.54 m from the ground level and the length of the drawbar is 1.8 m is set to allow the tractor to make a sharp turn without the rear tires fouling the trailer. The overall dimension of the trailer is 2.72 x 1.71 x 1.56 m (L x W x H). The tyre size is 7.5 X 16-8 PLY rating. Base plate of size 0.75 m^2 with thickness 20 mm which is bolted on the trailer platform frame. The gear box is made of cast iron with overall dimension of 0.35 x 0.35 x 0.32 m. A gearbox designed using a worm and worm-wheel is considerably smaller than one made from plain spur gears, and has its drive axes at 90° to each other. A worm gear is used for a large speed reduction ratio required between crossed axis shafts which do not intersect. A worm drive consists of a large diameter worm wheel (Spur gear) with a worm screw meshing with teeth on the periphery of the worm wheel. As the worm is rotated the worm wheel is caused to rotate due to the screw like action of the worm. The size of the worm gear set is generally based on the centre distance between the worm and the worm wheel. The worm wheel and worm gear is designed to rotate the full assembly in the gear ratio of 40:1. The fabricated gear box is bolted above the square plate to rotate the complete unit for 360^0. The turn table is heavy duty MS circular plate of diameter 0.65m and thickness of 20 mm which is fixed and bolted above the gear box shaft. In turn table 8 numbers large bearing balls are placed with equally distributed gaps. In that gaps grease is fully packed so as to make the rotation easy and to reduce friction. The view of the trailer assembly is shown in Fig. B.

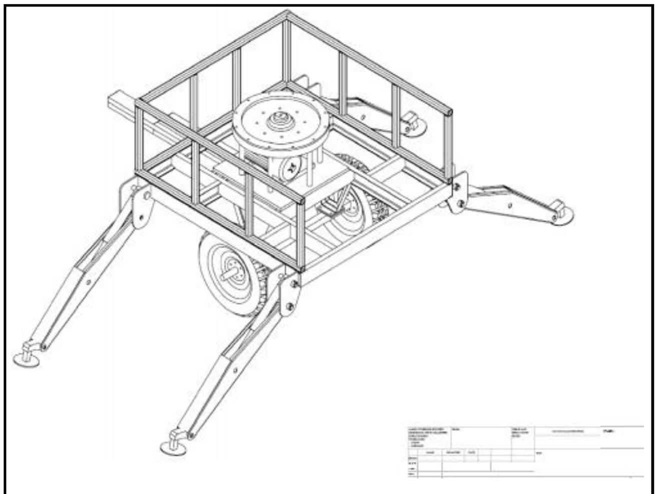


Fig. B : Trailer assembly

Ladder assembly:

In ladder assembly, the radial arm is made of heavy duty MS Square tube of size 0.25 x 0.25 x 0.005m for a length of 1.5 m. The one end Square tube is fixed and bolted vertically above the turn table and the other end is hinged with another square tube (Lower radial arm) of size 0.15 x 0.15 x 5 m. The one end Square tube is hinged to the lower radial arm and the other end is hinged to the upper arm of size 0.13 x 0.13 x 5 m of length of 6 m. The one end Square tube is hinged to the upper radial arm and the other end is hinged with bucket of size 0.75 x 0.75 x 1 which is of MS L angles with three sides closed and one side opened for entry purpose.

Hydraulic system:

Hydraulic tank or reservoir is closed type reservoir which is the integral part of a system. The reservoir tank act as the main oil container for the entire system. The reservoir is designed in such a way that to drain the old, used oil and contaminants from the tank. Oil filter is placed on the top of the hydraulic tank and same is connected to return line hydraulic hoses so as to filter the contaminants in the oil. Sight and level gauges offer an inside view of fluid levels in the hydraulic tank. Based on the design and requirement of oil for the operation an around 110 litre capacity tank was fabricated and placed with good structural support in front of the trailer which is 1.2 m above the ground level. The overall dimension of the hydraulic tank is 0.4 x 0.6 x 0.4 m.

Hydraulic pump are constant volume of fixed displacement pump and can work upto 175 bar pressure. They are relatively quiet and of simple construction. The pump is coupled to and driven by the prime mover of the system that is tractor PTO. The inlet side of the pump is connected to the reservoir: the outlet or pressure side is connected to the direction control valve and thus to rest of the system. The selected vane type pump is fixed on the trailer draw bar. This hydraulic motor used here is gerotor which is coupled with the gear box for rotation of complete assembly upto 360^0 on both the sides. Hydraulic motors can be instantly started, stopped, or reversed under any degree of load; they can be stalled by overload without damage. The most familiar double acting cylinder is the single rod end is used to lift the arm to the operational height. This type of cylinder provides power in both directions, with a pressure port at either end. In total there are six numbers of cylinders are used for the operations. In that four cylinders are fixed as stabilizers in both sides of the trailer in two ends of the left and right side.The four numbers of hydraulic cylinders are used as stabilizers for supporting, stability and safety for the operators at the time of operation. The diameter of the stabilizer cylinder bore and piston are 73mm and 40mm. There are other three cylinders which are hinged from lower radial arm to middle radial arm, middle radial arm to upper radial arm and upper radial arm to bucket. The function of the three cylinders are to lift the lower, middle and upper radial arms upto the height of 12m for the different operations like, coconut harvesting, fruit plucking, training, lopping etc. The diameter of the cylinder bore and piston are 100 and 50mm for the two cylinders.

Seamless tubes with high wall thickness, higher tensile strength, better bending quality, etc. are some of the specific properties which make such tubes most suitable for use in many high pressure hydraulic systems. Hence, for the operation of hydraulic ladder the seamless pipes with two sizes (22OD/18ID and 16OD/12ID). The 22OD/18ID pipes are used for inlet and outlet of hydraulic oil and 16OD/12ID pipes were used for the hydraulic cylinders and hydraulic motor. Each cylinder is controlled by a single valve expect the stabilizers. Two stabilizers are controlled by one valve and other two stabilizers by other valve and there is a separate valve for rotation of the turning table (full assembly). The arrangements are made in such a way that all the operations like stabilizing, lifting and rotation can be done by the operator at the time of operation in the bucket itself. The schematic view of the tractor mounted hydraulic operated ladder is depicted in Fig. C.

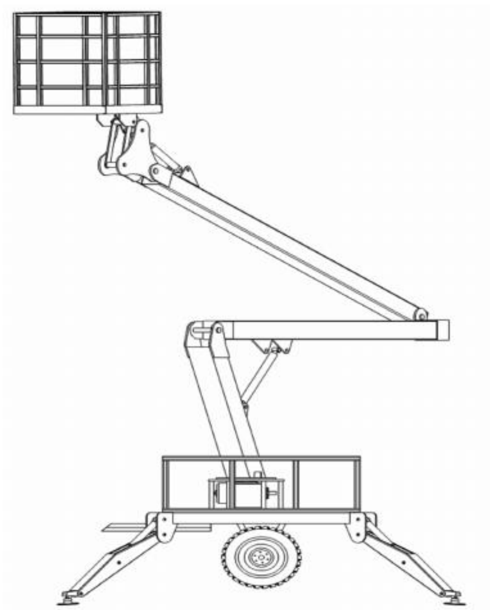


Fig. C : Schematic view of the hydraulic ladder

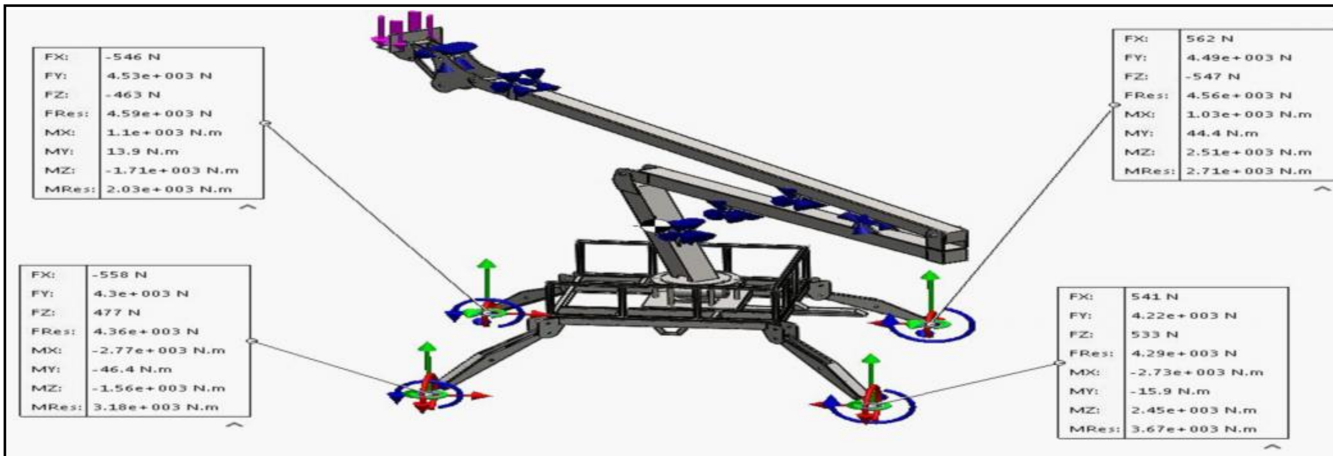
■ RESULTS AND DISCUSSION

The tractor mounted hydraulic operated ladder was developed with the above specification and view of the developed hydraulic ladder and different angle of rotation is presented in Fig. 1 and 2.

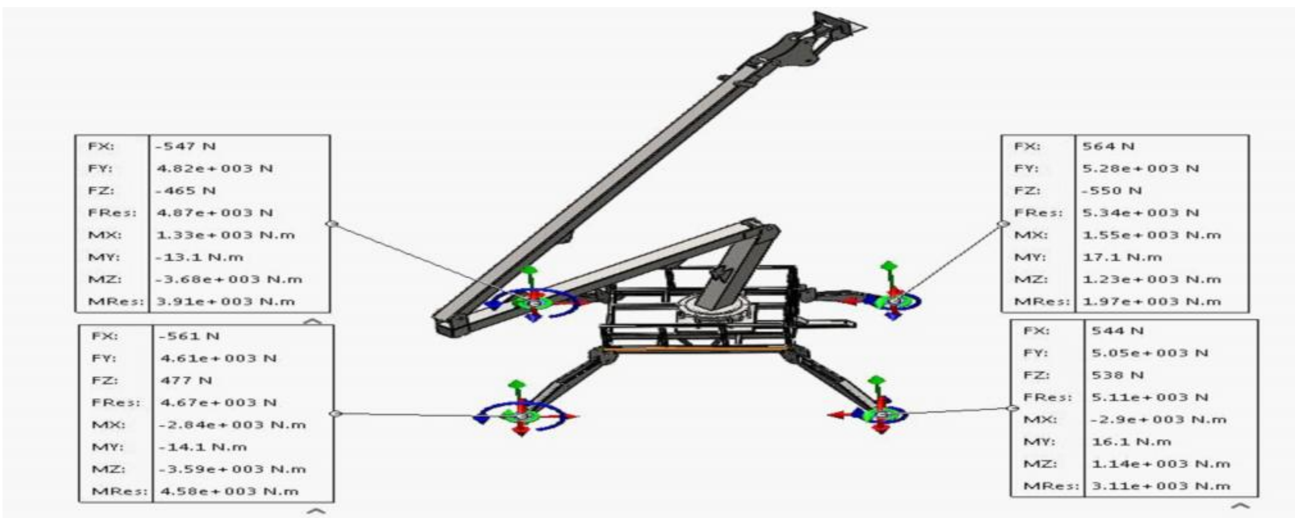
Testing the stability of the hydraulic ladder was done

Fig. 1 : View of the developed hydraulic ladder attached to tractor

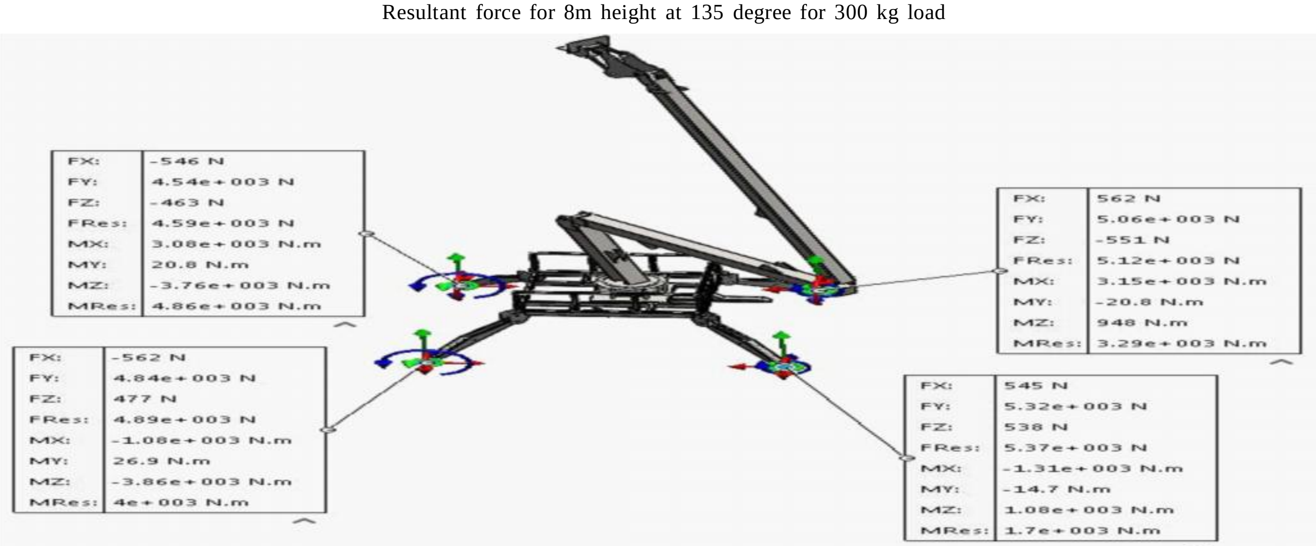
Fig. 2 : View of the developed hydraulic ladder at different rotation angles



Resultant force for 6m height at 45 degree for 75 kg load



Resultant force for 8m height at 135 degree for 300 kg load



Resultant force for 10m height at 45 degree for 75 kg load

Fig. 3 : Resultant force for different heights at different angle of rotation and different loads

by simulation method for finding the resultant forces acting on the four stabilizers L1, L2 and R1, R2. The simulation was done for the height of hydraulic ladder (two fold) from ground surface was kept constant at 6m. The values of the resultant forces for the different heights, different loads and different angle of rotation were are presented in the Table 2 and sample pictures are depicted in Fig. 3.

From the Table 1 it is observed that resultant force for 0 degree angle of rotation acting on the stabilizers L1, L2 and R1, R2 are increasing from 4180 to 5380 N for 6m, 8m and 10 m height as load increases from 75 kg to 300 kg. For 45 degree angle of rotation the resultant force acting on the stabilizers L1, L2 and R1, R2 are increasing from 4290 to 5550 N for 6m and 8m height whereas for the 10 m height the resultant forces are decreasing from 5370 to 4530 N as load increases from 75 kg to 300 kg. Resultant force for 90 degree angle of rotation acting on the stabilizers L1, L2 and R1, R2 are decreasing from 4170 to 4970 N for 6m height whereas for the 8 and 10 m height the resultant forces are increasing from 4670 to 5670 N as load increases from 75 to 300 kg.

Resultant force for 135 degree angle of rotation acting on the stabilizers L1, L2 and R1, R2 are decreasing from 4810 to 4210 N for 6m height whereas for the 8 and 10 m height the resultant forces are increasing from 4380 to 5420 N when the load increases from 75 kg to 300 kg. For 180 degree angle of rotation resultant force acting on the stabilizers L1, L2 and R1, R2 are decreasing

Table 1 : Resultant forces acting on the stabilizers

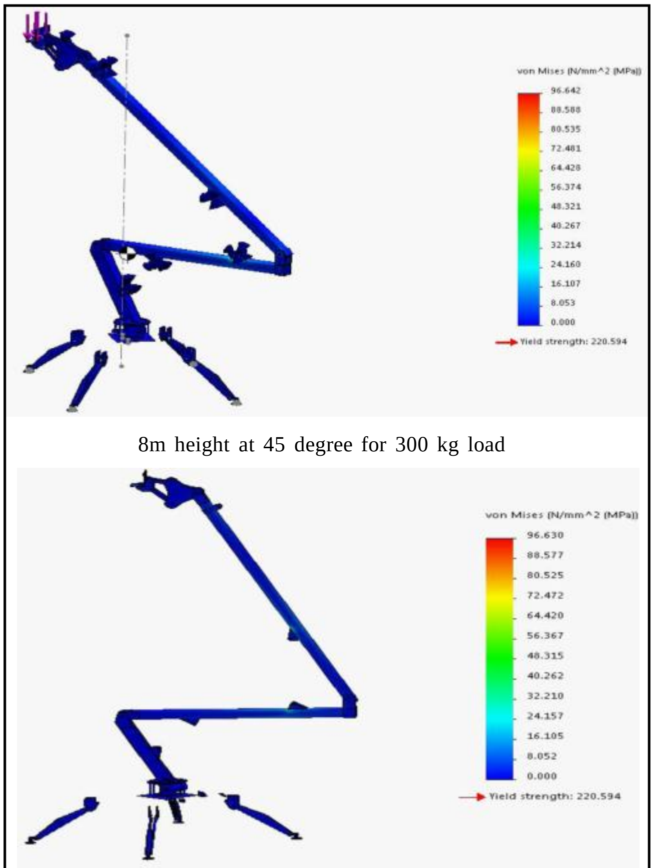
Sr. No.	Load, kg	Height m	Ø=0^0				Ø=45^0				Ø=90^0				Ø=135^0				Ø=180^0			
			L1	L2	R1	R2	L1	L2	R1	R2	L1	L2	R1	R2	L1	L2	R1	R2	L1	L2	R1	R2
1.	75	6.0	4220	4330	4180	4340	4290	4360	4560	4590	4380	4170	4750	4500	4260	4210	4450	4340	4440	4370	4390	4360
	150	6.0	4310	4450	4270	4410	4330	4540	4740	4910	4620	4570	4730	4670	4530	4420	4620	4470	4520	4410	4490	4410
	225	6.0	4320	4470	4290	4420	4380	4730	4920	5230	4730	4680	4870	4810	4610	4530	4690	4580	4590	4480	4570	4510
	300	6.0	4480	4990	4660	4720	4420	4910	5100	5550	4970	4840	4980	4940	4810	4690	4790	4690	4790	4710	4810	4680
2.	75	8.0	4460	4570	4520	4670	4470	4540	4680	4710	4670	4760	4830	4990	4920	4380	4960	4510	4530	4420	4480	4410
	150	8.0	4710	4980	4630	4810	4510	4620	4760	4860	4790	4940	4990	5090	5030	4480	5120	4680	4770	4690	4560	4490
	225	8.0	4890	5170	4940	5020	4720	4810	4840	4940	4930	5080	5110	5230	5090	4560	5230	4770	4890	4780	4780	4610
	300	8.0	4990	5350	5010	5130	4870	4950	5030	5120	5090	5170	5230	5310	5110	4670	5340	4870	5130	5010	4980	4840
3.	75	10.0	4510	4620	4830	4910	4750	4530	4680	4230	4760	4930	4820	5060	4530	4770	4760	4860	4760	4690	4760	4610
	150	10.0	4730	4890	4990	5090	4910	4620	4830	4370	4890	5170	4970	5310	4710	4810	4830	4970	4960	4890	4990	4840
	225	10.0	4860	4980	5110	5220	5160	4790	4970	4470	4940	5210	5120	5480	4850	5170	4910	5320	5110	5070	5160	4980
	300	10.0	5120	5170	5270	5380	5370	4890	5120	4590	5060	5420	5230	5670	4980	5350	4990	5420	5190	5120	5290	5170

Table 2: Variation of height with angle (¯)

Sr. No.	Included angle by the beam (θ), deg	Height of the bucket (H_R), mm ($H_R = L \sin \theta$)	Height of bucket from the ground level(H), mm $H = H_0 + H_R$
1.	15	1552	4802
2.	20	2052	5302
3.	25	2535	5785
4.	30	3000	6250
5.	35	3442	6692
6.	40	3857	7107
7.	45	4243	7493
8.	50	4596	7846
9.	55	4915	8165
10.	60	5196	8446
11.	65	5432	8682

from 5290 to 4360 N for 6, 8 and 10 m height as load increases from 75 kg to 300 kg with an interval of 75 kg. From the table it is found that the variations in the resultant forces are minimum for different heights, different angle of rotation and different varying loads. It is considered to be in a state of stability when no sign of overturning is evident with the hydraulic ladder in operation.

The static load for the hydraulic ladder is calculated from the solid works software through simulation module for different heights (8 and 10 m), rotation angles at 135 degree at 300 kg are depicted in Fig. 4.



8m height at 45 degree for 300 kg load

10m height at 45 degree for 300 kg load

Fig. 4 : Von mises stress for different height at 45 degree for 300 kg

It is observed from the Fig. 1 that the limiting strength for yield stress is 220.59 N/mm^2. Whereas the maximum stress occurred is 96.64 N/mm^2 for the 8m height and 96.63 N/mm^2 for the 10m height at 135 degree for 300 kg load for refined hydraulic ladder. The maximum stress occurred in the 8m and 10 m is less than the yielding stress. Similar types of experiments were repeated for different heights (8 and 10 m) by lifting the platform, different angle of rotation (45, 90, 135 and 180 degree) and different loads (75, 150, 225 and 300 kg) and the maximum stress was noted. The stress noted in the above said variables for the hydraulic ladder is less than the yielding stress.

Mechanical performance of the hydraulic ladder:

Factor of safety:

The factor of safety of any mechanical device is the ratio of maximum load bearing capacity to the theoretical or design load bearing capacity. The value of factor of safety must be greater than or equal to 2.

$$\textbf{Factor of safety} = \frac{\textbf{Maximum load on main beam (S + V)}}{\textbf{Theortical load}} \ldots\ldots\ldots \text{i}$$

Where,

S = Static load (load of bucket and main beam load)

V = Variable load (men loads, fruit load).

The equipment has been designed in such a way that the main beam could able to bear the variable weight of around 100 to 150 kg which is to be considered as the weight of the person on bucket. But this has been demonstrated pragmatically that the equipment is capable of lifting effectively 300 kg *i.e.* the weight of two persons and fruits. This is therefore clear (eq. i) that the factor of safety of the equipment greater than 2.

Height vs. Angle:

The height of the platform excluding the height of the person can be plotted X-Y plane with the angle displaced by the main beam from the horizontal. This can easily be realized that a circular path is followed by the platform while it moves up or down. The cage is kept at the height of 3250 mm from the ground level. At the same time the angle made by the main beam is 10^0 from the horizontal.

The instantaneous relationship in between height and angle for a particular time can be given by the formula:

$$H_R = L \text{ Sin } \theta \qquad \ldots. \text{(i)}$$

where,

$-H_R$ = Height of the platform from its reference minimum height H_0

L = length of the upper arm *i.e.* 6000 mm

θ = Included angle by the beam from horizontal

The reference height of the platform *i.e.* H_0 is equal to 3250 mm which can be calculated by adding the vertical heights of the ladder and sine of 10^0 of the beam length.

Therefore H_0 = 3250 mm (approx.).

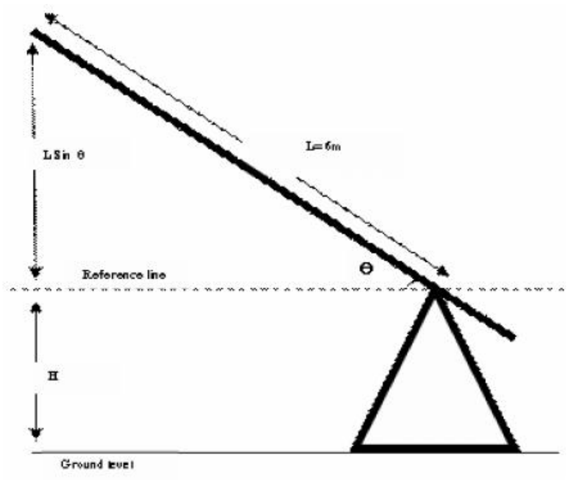


Table 2 shows the height increased from the reference height H_o in each 5^0 variation of included angle by the beam from the horizontal.

The estimated maximum height of the platform from the ground level is 8682 mm (28.9 feet) which can be achieved at the angle of 65^0 in the upper radial arm. Since this machine contains two arms (lower and upper arm) where one arm (lower) is used for lowering the bucket for the operators stepping in and stepping out and this lower arm also increases the height by 1m so as to increase the vertical height for the upper arm. By adding this 1m height, the total maximum height can be achieved by this machine is 9692 mm (32.3 ft.) makes an angle of 65^o with reference line. No further height could be achieved beyond an angle of 65^o and hence, the angle of elevation is restricted to 65^o.

Conclusion:

Variations in the resultant forces are minimum for different heights (6, 8 and 10m), different angle of rotation from 0-180° at an interval of 45 and different varying loads 75, 150, 225 and 300 kg, respectively. It is considered to be in a state of stability when no sign of overturning is evident with the hydraulic ladder in operation.

The maximum stress observed in the hydraulic ladder for, 8m and 10 m height with different loads and different angle of rotation is 96.64 N/mm^2 which is less than the yielding stress which is 220.59 N/mm^2.

The hydraulic ladder is mounted on the trailer with stabilizing system for supporting, stability and safety for the operators at the time of operation.

The hydraulic ladder is developed in such a way that it can be rotated from 0 to 360 degree both in clockwise and anticlockwise direction so that minimum 4 coconut/ mango trees can be covered by simply operating the directional valve.

It is observed that the equipment has been designed in such a way that the main beam could able to bear the variable weight of around 100 to 150 kg which is to be considered as the weight of the person on bucket and the factor of safety of the equipment greater than 2.

The estimated maximum height of the platform from the ground level is 9682 mm (32.3 feet) which can be achieved at the angle of 65^0 in the upper radial arm.

The hydraulic ladder is suitable for harvesting of mango and coconut orchard upto 10 m, pruning of tree upto 10 m height comfortably and spraying over the tree canopy upto a height of 10 m.

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