International Journal of Science, Environment and Technology, Vol. 6, No 3, 2017, 2087 – 2099

ISSN 2278-3687 (O)
2277-663X (P)

DESIGN, DEVELOPMENT AND LABORATORY TESTING OF A FRONT MOUNTED THREE POINT LINKAGES FOR HIGHER POWER TRACTORS

Naseeb Singh[1*] and K.P. Pandey[2]

[1*]Research Scholar, C/o Prof. V.K. Tewari, [2]Professor, K.P. Pandey,
Department of Agricultural and Food Engineering, IIT Kharagpur,
West Bengal, India – 721302
E-mail: naseeb501@gmail.com (**Corresponding Author*)

Abstract: With a view to fully utilize the available power, reduce soil compaction and for timeliness of tillage operations, a front mounted three point linkages was designed for higher power tractors. Front mounted implements make it possible to perform two operations in a single pass, using both a front and a rear mounted implements. It consists of top link on upper arm, two lower links attached with hydraulic cylinders to move up and down and side brackets to mount whole assembly on front of tractor. A finite element analysis (FEA) using ANSYS simulation software was done to determine the stress and deformation produced in different components. Laboratory testing of developed three point hitch was done to find the lift capacity and range of movement of linkages. The lift capacity of front three point linkages was found to be 2187 kg at lower hitch point and 1893 kg at standard frame at 17 MPa pressure. Lift and movement range were measured and found to satisfy the requirement of category-II hitch given in ASAE S513 FEB03.

Keywords: Front three point linkage; Finite element analysis; Hydraulic cylinder; Lift capacity; Draft.

1. Introduction

The biggest challenge before the agricultural sector of India is to meet the growing demands of food for its increasing population from 1.22 billion in the year 2010 to 1.46 billion by the year 2030 [1]. Since the cultivated area has remained nearly constant (within 138 to 142 Mha) over the years, the only option to increase food production is to increase the productivity of land [6]. This can be achieved by increasing cropping intensity and reducing turnaround time through increased mechanization. Farm power availability in India during the last 50 years has increased from 0.30 kW/ha in 1960-61 to about 1.73 kW/ha in 2009-10 [9]. India is the largest producer of tractors with 5.45 lakh of tractors in 2011 increased from 3.46 lakh in 2008 [2].

In search of higher productivity, farmers are taking more than two crops in a year. In this farming pattern they don't have much time for field preparation. Front-mounted implements

*Received May 24, 2017 * Published June 2, 2017 * www.ijset.net*

make it possible to perform two operations in a single pass, using both a front and a rear mounted implements. The purpose of a tractor is to convert fuel power into useful power at drawbar or hitch point with producing sufficient traction. The hitch itself is defined as a single articulated point or combinations of articulated points and links through which tractor delivers tractive effort in the form of pull or push to counteract a draft force of an implement or draft producing body. Hitch point may be in rear, front or side of a tractor [8]. Front-mounted implements have several potential advantages. First, the driver can easily see the implement. Second, soil compaction gets reduced resulting in increased productivity. Third, due to multiple pass effect the fuel consumption and tractor operating hours are decreased [5].

So, by keeping the above facts in mind present study was undertaken with the objectives of designing the front mounted three point linkages for higher power range tractors and evaluates its performance by doing laboratory testing. The paper is organized as follows: in section 2, materials and methods are explained i.e. design of three point linkage, determination of links points, length of various links, finite element analysis and lift capacity measurement procedure; in section 3, the experimental results are discussed to show the feasibility of the front linkages; in section 4, conclusions are drawn.

2. Material and methods

The designed front mounted three point linkage is different from conventional rear three point hitch system as it consists of two hydraulic cylinders for movement of lower links and no draft sensing link is provided. Lower links are converging rearwards as convergence forwards of the links causes the rear of the implement to be lifted more than the front and results in problems of clearance at the front of the implement [10].

Auxiliary pump is used to provide hydraulic power to the cylinders. The detail design calculations for deciding the dimensions of links, links points and size of hydraulic cylinder are made in the following section. A Pro-E model of front three point hitch assembly is shown in Fig. 1.

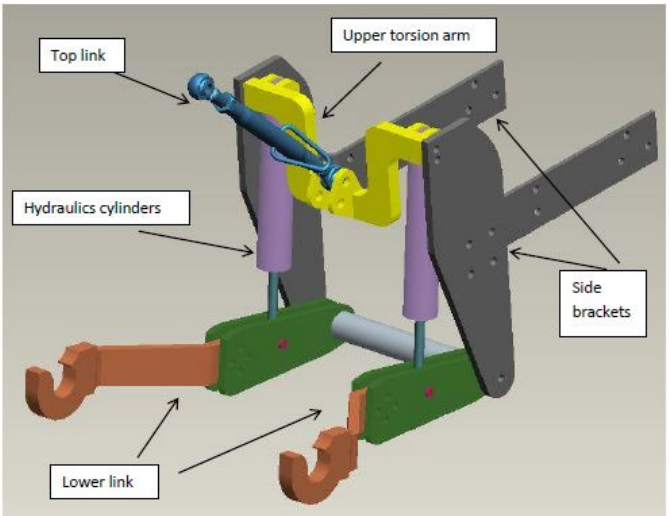

Fig. 1. Front three point hitch assembly

2.1 Design of three point linkage

The design of each component was done based on maximum forces experienced for two cases, (i) working with a matching size MB plough and, (ii) for lifting a specified load on standard frame.

2.1.1 *Prediction of draft*

By using ASABE draft Eq. (1), the draft for MB plough was predicted,

$$D = F_j\,[A + BV + CV^2]\,WT \tag{1}$$

Where, D = Draft (N); F = dimensionless soil texture adjustment parameter; j =1 for fine, 2 for medium and 3 for coarse textured soils; A, B and C = machine-specific parameters; V = field speed, (km/h); W = machine width, (m); T = tillage depth, (cm).the values of different co-efficient are provided in ASAE D497.4 [3].

2.1.2 *Forces acting on front linkages while working with MB plough*

While tractor moves forward, it pushes the implement through soil and forces acting on linkages during this are shown in Fig. 2.

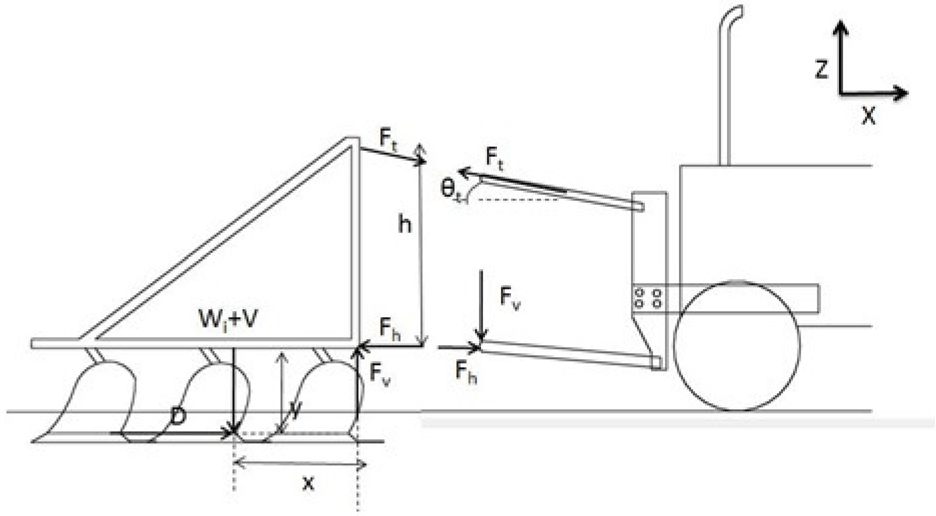

Fig. 2. Forces on front linkages.

By taking moment about upper hitch point and lower hitch point on implement, we get Eqs. (2)-(5).

$$F_h = D\left(1 + \frac{y}{h}\right) + \frac{(W_i + V)x}{h} \tag{2}$$

$$F_{t\cos\theta_t} = \frac{Dy}{h} + \frac{(W_i + V)x}{h} \tag{3}$$

$$F_V = W_i + V + F_t \sin\theta_t \tag{4}$$

$$F_h = D + F_t \cos\theta_t \tag{5}$$

Compressive and bending forces on lower link are determined by resolving horizontal force along the direction of motion and vertical force on each of lower link as shown in Fig. 3.

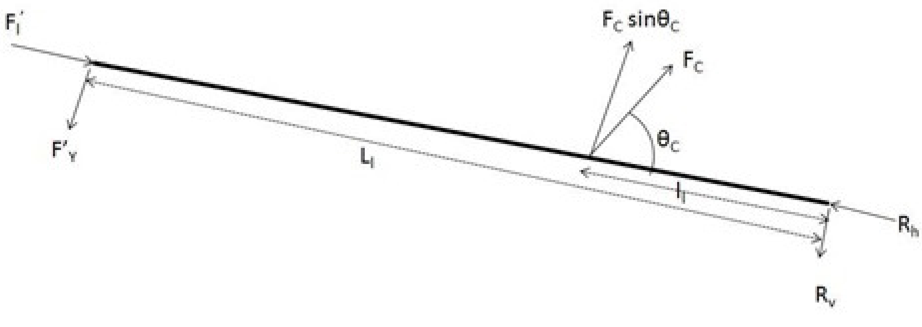

Fig. 3. Forces on front lower link.

Eqs. (6) and (7) are used to express the compressive and bending forces in lower links and Eq. (8) is used to calculate the force in hydraulic cylinder rod.

$$F_l = \frac{F_h \cos\theta_h + F_V \sin\theta_h}{\cos\theta_V} \tag{6}$$

$$F_y = \frac{F_V \cos\theta_h - F_h \sin\theta_h}{\cos\theta_v} \tag{7}$$

$$F_c = \frac{F_y'}{sin\theta_c} \times \frac{L_l}{l_l} \tag{8}$$

2.1.3 *Forces acting on front linkages while lifting a specified load*

Fig. 4shows forces acting on front links while lifting a specified load. W_{LF} be the lift capacity at 610 mm away from hitch point.

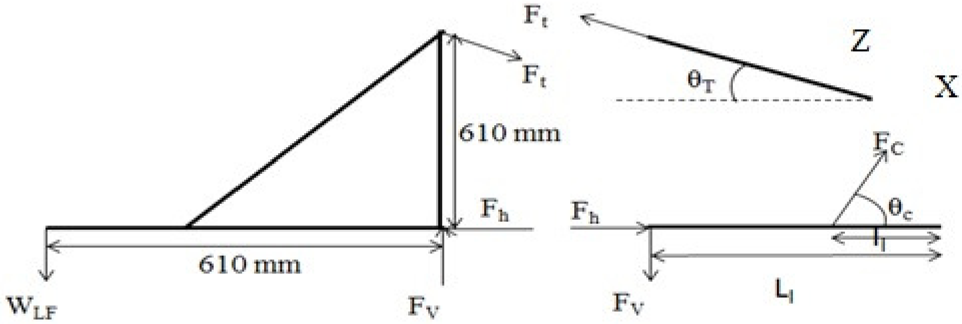

Fig. 4. Forces in front linkages while lifting a specified load.

Eqs. (9)-(12) were used to calculate the forces on each linkage,

$$F_t = \frac{W_{LF}}{cos\theta_t} \tag{9}$$

$$F_V = W_{LF} + F_t \times sin\theta_t \tag{10}$$

$$F_h = F_t \times cos\theta_t \tag{11}$$

$$F_c = \frac{F_V}{l_l} \times \frac{L_l}{sin\theta_c} \tag{12}$$

After calculating the forces on linkages assuming both cases, maximum force was considered for designing front three point linkages.

2.1.4 *Design of bent lower link*

Forces acting on bent lower link are shown in Fig. 5.

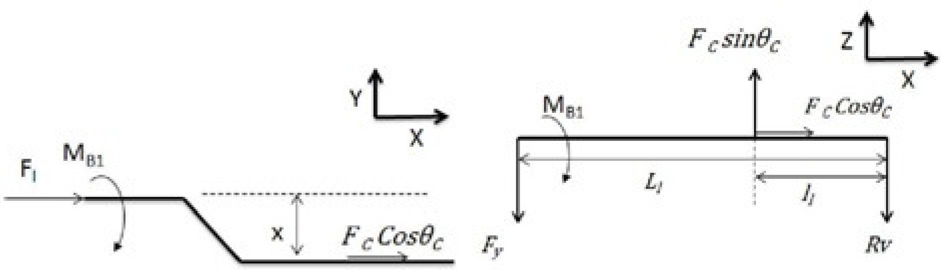

Fig. 5. Forces acting on bent lower link.

Let M_{B1} and M_{B2} are the bending moment due to force F_y and F_l as given in Eqs. (13) and (14).

$$M_{B1} = F_y \times (L_l - l_l) \tag{13}$$

$$M_{B2} = F_l \times x \tag{14}$$

So, resultant bending moment is given by Eq. (15).

$$M_B = \sqrt{M_{B1}^2 + M_{B2}^2} \tag{15}$$

Maximum stress produced in lower link is expressed as in Eqs. (16) and (17).

$$\sigma_{max} = \sigma_{compressive} + \sigma_{bending} \tag{16}$$

$$\sigma_{max} = \frac{M_B \times 6}{bd^2} + \frac{F_c \times cos\theta_c}{bd} \tag{17}$$

Where, b and d are the thickness and width of lower link respectively.

2.1.5 *Design of top link*

If D and d are the outer and inner diameters of adjusting tube of top link and σ_t is the allowable stress then, using Eq. (18), the value of D and d can be calculated.

$$\sigma_t = \frac{F_t}{\frac{\pi}{4} \times (D^2 - d^2)} \tag{18}$$

2.1.6 *Design of actuator*

If F_c is the force applied by each cylinder, then rod diameter (d) and bore diameter (D) of hydraulic cylinder is expressed as in Eqs. (19) and (20).

$$d = \sqrt{\frac{2 \times F_c}{\pi \times \sigma}} \tag{19}$$

$$D = \sqrt{\frac{2 \times F_c}{\pi \times P} + d^2} \tag{20}$$

Where, P is the hydraulic pressure of system.

2.2 Determination of link points and length of various links

According to standard ASAE S513 FEB 03 [4], the distance, L, from the front end of the PTO to the center of the lower hitch points (with the lower link horizontal) should be between 550 mm to 625 mm. Also, according to standard ISO 730/1 [7] the top link angle should be 10°- 15° when the lower link is horizontal. By keeping these in view, the links geometry at different positions is drawn to find link points and links length as shown in Figs. 6-8.

From Figs. 6-8, link points and length of links can be calculated by using Eqs. (21) – (23).

$$y_1 = TH - (x_1 + L) \times sin\theta \tag{21}$$

$$y_1 = GH + (x_1 + L) \times sin\varphi \tag{22}$$

$$T_l = \frac{(L-z)}{cos15^\circ} \tag{23}$$

Links point of top link = (x_1+z) from LLP (front)

Where, z = distance between top link point and end of front PTO

T_l = length of top link

GH = maximum distance of LHP from ground

TH = transport height

By solving Eqs. (21) and (22), the values of x_1 and y_1 will be obtained. So, using x_1 and y_1, the link points and length of all linkages can be calculated.

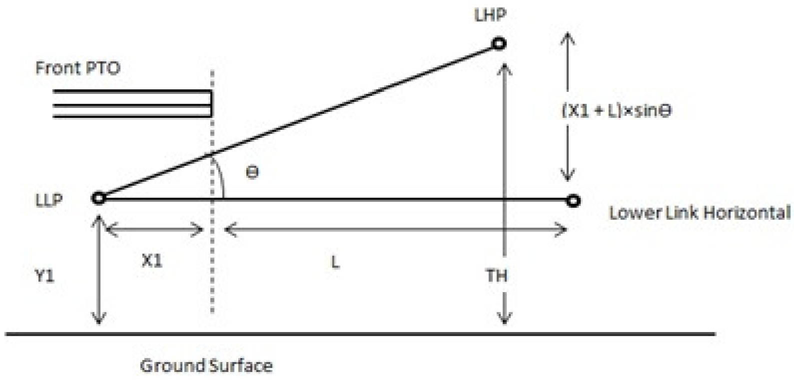

Fig. 6. Geometry of lower link at maximum height.

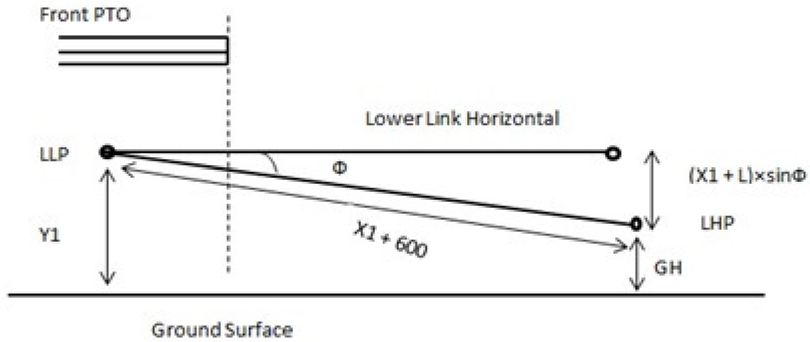

Fig. 7. Geometry of lower link at minimum height.

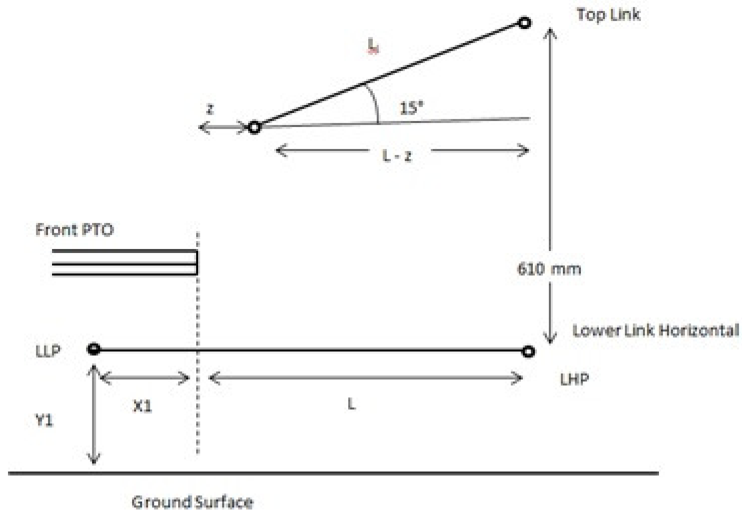

Fig. 8. Geometry of top link with lower link horizontal

2.3 Finite element analysis of front three point linkage

Forces acting on linkages and brackets were calculated and after designing the front three point linkages, finite element analysis was done using ANSYS 14.0 software for front three point linkage to find the stress and deformation produced in different components.

2.4 Procedure for lift capacity measurement of front three point linkage

Front axle was supported and secured in horizontal position by jacks so that the front wheels do not deflect while testing. Standard frame was mounted on front three point hitch system. A load cell was attached at a distance of 610 mm away from lower hitch point. The other end of load cell was fixed rigidly. Three point linkage was lifted with the help of spool valve arrangement and the reading of load cell was noted down with the help of load cell indicator till the relief valve started to blow.

Precaution was taken that the load cell must be vertical and the testing platform must be horizontal. The reading was taken at six different positions. The minimum reading of the load cell from the six positions was taken. Its equivalent load at 90% of relief valve pressure will be the lift capacity throughout range, while the load at 90% equivalent of relief valve pressure at horizontal position will be the lift capacity at horizontal position. A similar procedure was used for lift capacity at hitch point by removing the standard frame and fixing the load cell directly to lower link through a drawbar.

For measuring the lowering and lifting time of front three point linkages a drawbar was attached to the lower links and spool valve control lever was operated to lower and lift the lower links and time taken in lowering and lifting were measured with the help of stop watch. This procedure was repeated at different engine speeds. Fig. 9 shows the lift capacity measurement at lower hitch point.

Fig. 9. Lift capacity measurement at lower hitch point.

3. Results and Discussion

The forces acting on linkages and brackets of front three point linkages while working with three bottom MB plough were calculated and finite element analysis of components of front linkages was done using ANSYS 14.0 software. Figs. 10-12shows the stresses in different components of front three point linkages and front axle support (FAS).

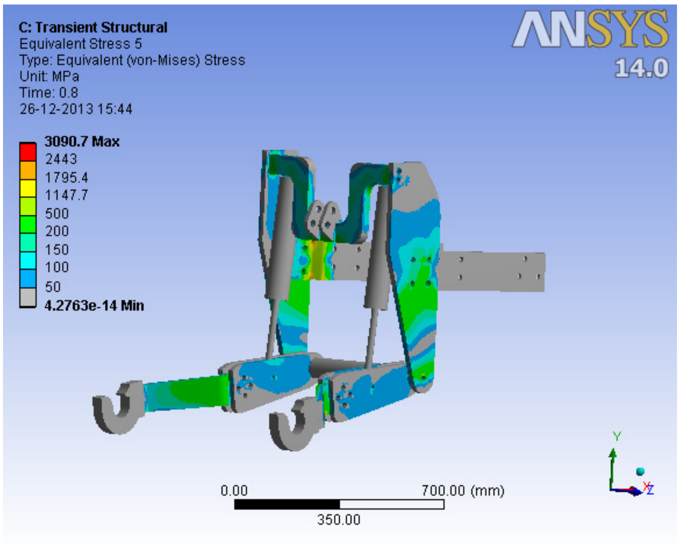

Fig. 10. FEA of complete assembly together.

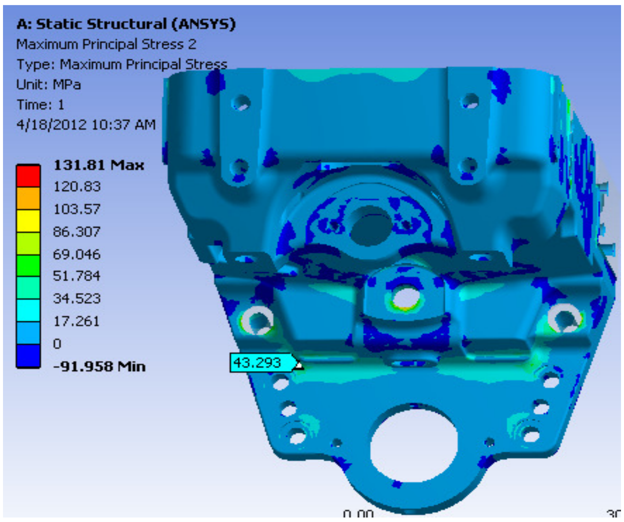

Fig. 11. Equivalent stress produced in FAS assembly.

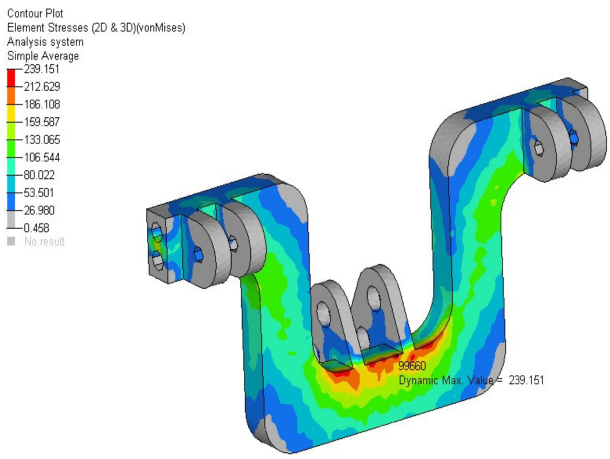

Fig. 12. Equivalent stress produced in upper torsion arm.

Results of finite element analysis are shown in Table 1.

Table 1: Summary of FE analysis of front three point linkage

Component	Material	Yield Strength (MPa)	Max. equivalent stress (MPa)	Remarks
Lower Link	EN 47	1034	399.3	Safe
Side Brackets	EN 47	1034	441	Safe
Cylinder Rod	AISI 1045 Steel	310	148.33	Safe
Upper Torsion Arm	45C8	320	239.15	Safe

As shown in Table 1, each component is safe against their yield strength as factor of safety is above 2.5. So, fabricated three point linkage will be safe against mechanical stresses. Time required in lifting and lowering of front lower link was measured and compared with the calculated value. The minimum time required for lifting and lowering at rated speed were 3.33 sec. and 3.89 sec. respectively whereas at 1100 rpm engine speed, time required were 6.05 sec. and 6.98 sec. respectively. Table 2 describes the time required in lifting and lowering at different engine speeds and compared with calculated value. The difference between measured and calculated value may be because of friction losses in hose pipes, due to hydraulic fluid turbulence and error in time measurement.

Table 2: Time required in lifting and lowering of front lower link

Engine speed (rpm)	Lifting time (sec)		Lowering time (sec)	
	Measured	Calculated	Measured	Calculated
2000	3.33	3.36	3.89	3.92
1500	4.41	4.49	4.99	5.22
1100	6.05	6.126	6.98	7.128

Table 3 shows the results of lift capacity performance. The lift capacity throughout range at lower hitch point and at standard frame were 2410 kg and 1893 kg respectively whereas lift capacity at horizontal position at lower hitch point and standard frame were 2725 kg and 2187 kg respectively.

Table 3: Lift capacity performance of front three point linkage.

Characteristics	At standard frame	At lower hitch point
At Horizontal	2187 kg	2725 kg
Throughout range	1893 kg	2410 kg

By studying Table 3 we can say that the lifting capacity of front three point linkages satisfied the minimum lifting capacity recommended by ISO 730/1 [7] and it is adequate for given range of tractors to perform various operations of on-field and off-field. Table 4 shows the lift and movement range of designed front three point linkage.

Table 4: Lift and lift height range of front three point linkage

Particulars	Dimensions (mm)
Lower hitch points height above supporting surface	176
Power range	762
Transport height (lower hitch point axis horizontal throughout)	938
Lower hitch point clearance	100

Lift and movement range were found to satisfy the requirement for category-II hitch system.

4. Conclusions

Based on the results of the study the following conclusions were drawn:

1. Stress and deformation produced in all the components of front three point linkage were less than the allowable stress and elongation of their respective material. So, design is safe against mechanical stresses and deformation.
2. Lift and movement range were found to satisfy the requirements of category-II hitch as specified in standard ASAE S513 FEB03 [4].
3. Lift capacity of fabricated front three point linkages at the lower hitch point was found to be 2187 kg while the same at standard frame was 1893 kg throughout its operating range.
4. The minimum time required for lifting and lowering at rated speed were 3.33 seconds and 3.89 seconds respectively.

References

[1] Anonymous, 2013. Demographic overview-India, International database, United States Census Bureau, http://www.census.gov. (Last accessedon March17, 2015).

[2] Anonymous, 2012. Indian tractor industry, Cyclical moderation in growth ahead. ICRA rating feature. ICRA Limited Gurgoan.

[3] ASAED497.4, 1999. Agricultural Machinery Management Data. ASABE St. Joseph, Mirch.

[4] ASAE*S513, 2003. Agricultural wheel edtractors-Front–Mounted Linkage. ASABE St. Joseph, Mirch.

[5] Bharti, C.K., 2012. Feasibility study of better utilization of tractor power using front three point linkage. Unpublished M.Tech. Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur, India.

[6] Datta, S.K., 2012. India, Agriculture and ARD. Global Conference on Agricultural Research for Development. Indian Council of Agricultural Research, Delhi. India.

[7] ISO 730-1, 1994. Agricultural wheeled tractors - Rear-mounted three-point linkage – Part 1: Categories 1, 2, 3 and 4.

[8] Morling, P.E., 1979. Agricultural tractor hitches analysis of design requirements. ASAE Distinguished lecture series 5.

[9] Singh, S.P., Singh, R.S., and Singh, S., 2011. Sale trend of tractor and farm power availability in India. Agricultural Engineering Today, 35(2): 25–35.

[10] Thompstone. G., and Cowell. P.A., 1990. The Influence of front linkage geometry on tractor implement interaction. Journal of agricultural engineering research.45,175-186.

Nomenclature

Sym.	**Description**	**Sym.**	**Description**
2WD	Two wheel drive	l_l	Distance between LLP and point where cylinder is attached to lower link
b	Thickness of lower link	M_B	Bending moment
d	Rod diameter; Width of lower link	PTO	Power take off
F_c	Force applied by each cylinder	V	Field speed
F_l'	Force on each lower link along its length	V_i	Vertical component of soil reaction force for condition i
FEA	Finite element analysis	W_i	Weight of implement in condition i
F_h	Force in lower link in horizontal direction along the direction of motion	x	Moment arm of resultant vertical soil and gravitational force on the implement about the cross shaft
FAS	Front axle support	x_f	Distance between implement center of gravity and front axle
F_t	Force in top link	y	Height of cross-shaft from center of resistance
F_v	Vertical force on lower link	θ_c	Angle between lower link and axis of cylinder
h	Mast height	θ_h	Angle of lower link with horizontal
LLP	Lower link point	θ_t	Angle of top link with horizontal
LHP	Lower hitch point	θ_v	Angle of lower link with direction of motion in horizontal plane
L_l	Length of lower link	σ	Allowable stress of material
F_l	Compressive force on lower link	F_y	Bending force on lower link
F_c	Force in cylinder rod		