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Development of High Clearance Unit in Small Tractor for Cotton Crop

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Agriculture is one of the major sectors in Indian economy. Nearly 60 per cent of the population depends on agriculture and it is considered as backbone of the country. Cotton 'the white gold' is one of the most important commercial crops playing a key role in the economical, political and social affairs of the country. The existing clearance of the small tractor was increased with developed high clearance unit using mild steel as a structure. The tractor was lifted up to height of 1.4m using front and rear legs of front axle and rear axle. A frame was developed to support the tractor weight and dynamic loads of the legs were provided for all the wheels for motion. The drive from the tractor rear axle was transferred to the rear wheels using chain and sprocket arrangement for both the rear wheels. The front legs of front wheels and rear legs of rear wheels were connected using horizontal bar for proper supporting and load distribution. The dynamic analysis of the tractor with weeding and spraying unit was studied and found that, the tractor was in stable condition during operation up to a depth of 10 cm. It was found that the location of centre of gravity of tractor was1.9 m from the ground surface. The critical speed of tractor is 2.55 m/s and the front and rear wheel reactions are about 2045.38 N and 7813.66 N respectively at maximum depth of operation.

Key words: *Cotton crop, High clearance tractor, Stability, Tractor dynamics*

Agricultural mechanisation plays a key role in improving agricultural production and productivity in developing countries. The average farm size in India is small and marginal land holdings account for 85% of total land holdings. Mechanizing small and non-contiguous group of small farms is against 'economy of scale' for individual ownership of farm machinery. The status of farm mechanisation analysed by the trend in growth of mechanically power- operated farm equipment over traditional human and animal power operated equipment. The available farm power and productivity in India are expected to reach 2.2 kW ha^{-1} and 2.3 t ha^{-1} respectively by the year 2020 (Mehta *et al*. 2014).

In addition, tractorization in India, lead to many changes in basic tractor design and development of many forms of tractor based on the utility emerged. In such development to focus the small and marginal farmers, small holding and its intercultural requirements, ***small tractors*** are introduced with both 4wheel drive and 2wheel drive in the range between 18.3 hp and 25 hp.

The adoption of machine in farming operation is increasing day by day as it resulted in saving of cost of production and increasing net income of the farmers. The farming operations are labour intensive. Even though population of India is more, there is acute shortage of manpower for farming operations. The operational cost of human energy is more as compared to the machine energy in farming due to drudgery involved. The use of machine in farming operations have resulted in sustainable growth with lowering the cost of operation. In present situation, mechanization is in increasing demand (Khambalkar*et. al*. 2012).

MATERIAL AND METHODS

Selection of components for high clearance unit

Main frame

The selection of the material is very important for design of the high clearance unit, since it has to support the total weight of prime mover and be stable under various dynamic load conditions. Mild steel channels (medium carbon steel) used for constructing main members and M.S pipes used for braces and supporting members.

Development of framed structure for high clearance unit

The structural channel was consisting of a trapezoidal section as major supporting platform. The frame dimension of rectangular channel was 1200 mm length, 50 mm width and 5 mm thickness. This platform consists of two rectangular hollow channels and two square hallow channels are combined as one unit, each section has individual dimensions and were welded to form trapezoidal platform. The structure has high torsion rigidity and more strength and stiffness. These sections are joined and welded with the suitable joints and designed such that the total weight of the tractor loaded at the centre of this trapezoidal section.

Design of legs for rear wheels

Mild steel channels were used for designing of rear wheel legs in the high clearance unit. Depending upon the observed average cotton crop height the lengths were selected for fabrication of rear raisers. The length, width and thickness of the hollow section were 140 cm, 40cm and 0.5cm. The two legs are fabricated as per the required dimensions. These two legs were connected by the square hollow channel frame for supporting the legs and this channel was connected by trapezoidal section of frame and fastened to the supporting members. The rear leg channel was shown in the Fig 1.

Development of drive assembly for rear wheels

Important component of the high clearance unit is the final drive arrangement from rear wheels of mounted tractor to drive wheels of the unit. The main drive to the rear wheels through raised channels given with chain and sprocket. These sprockets mounted on the two shafts top and bottom on well supported bearings within the channel. Four sprockets were arranged in the rear channel. The dimensions of the sprockets were 150 mm diametre and 20 mm thickness. The sprocket was divided into 12 divisions. After arrangement of gears, the chains were fixed on the teeth. The length of the chain was 2400 mm and width of the chain was 50 mm and thickness was 35 mm.

Arrangement chain and sprockets

The chains are mostly used to transmit motion and power from one shaft to another shaft, when the centre distance between the shafts is short. In order to obtain a constant velocity ratio, chain drive is mostly preferred.

The length of first chain (L) attached from ground wheel to 1st idler sprocket was calculated as (Shah and Jadvani, 1990):

$$L = p\left[\frac{n_1 + n_2}{2} + \frac{\left(\operatorname{cosec}\frac{180^o}{n_1} + \operatorname{cosec}\frac{180^o}{n_2}\right)^2}{4m} + 2m\right]$$

L= length of chain,
n_1, n_2 = number of teeth on sprockets 1 and 2
p = pitch diameter

These gears and chains of designed sizes selected from the market available ISO standard range. Components of sprocket and chain and assembly of chain and sprocket to the rear wheels was as shown in the Fig 2.

Design of legs for front wheels

For fabrication of front wheel legs arrangement, the square structural pipe members were used and joined with connecting members. The rectangular square hollow channel was considered for fabrication of front legs frame. The frame dimension of square channel was 1200 mm length, 50 mm width and 5 mm thickness. The two legs were chosen for computed height of the crop and the legs were fixed and welded at the desired height. These two legs were joined with the help of supporting centralsquare channel its dimensions were 70 x 70mm and thickness 5 mm. At the centre of horizontal square frame, circular wholewas provided for incorporating the circular pivot shaft of diametre 30 mm and 150 mm length. The total arrangement of the front channel and supporting pivot was as shown in the Fig 3.To provide turning movement to the front wheel arrangement was made through a runner and fixed into the square rectangular hollow channel and connected to the front wheel hub at the bottom of the runner.

Wheel hub arrangement

The wheel hub along with flange was made up of medium carbon steel material. The arrangement of hub was to attach the front wheels and connected to guiding runner which transmit twist from top to down to direct the wheel position and helps in turning of tractor. The hub arrangement was as shown in Fig 4.

Arrangement of steering system with high clearance unit

The steering system was altered to the selected tractor and to providestearability to the tractor on high clearance. The four wheel drive of selected tractor was limited to the two wheel drive by giving the drive to rear wheels only. Since the stearability along with drive to front wheels of high clearance set up was little complicated and hence, the existing steering setup of the tractor front wheel was shifted to forward by altering the push rod assembly for newly designed tie rod ends of steering system and also connected to drop members of front wheel assembly as shown in Fig 5. These drop members were in turn fixed to the front wheel hub so as to provide direction as per the movement of steering wheel system.

Arrangement of bearings at rear wheels

The square bearings were used for rear wheel legs.The dimensions of the bearings are 10 cm length and 10 cm width. Each shaft, both sides of the rear channel four bearings were arranged. These bearings were made up of stainless steel material sealed bearings.

Centre of gravity of developed high clearance tractor

Procedure:

Centre of gravity of tractor refers to a point on the body of tractor at which its weight is acting. In rear wheel drive tractors it is usually located at about

Fig 1. A view of rear legs

Fig 2. Arrangement of chain and sprockets for rear wheels

Fig 3. A view of front legs

Fig 4. Arrangement of wheel hub for front wheels

Fig 5. Arrangement of steering system

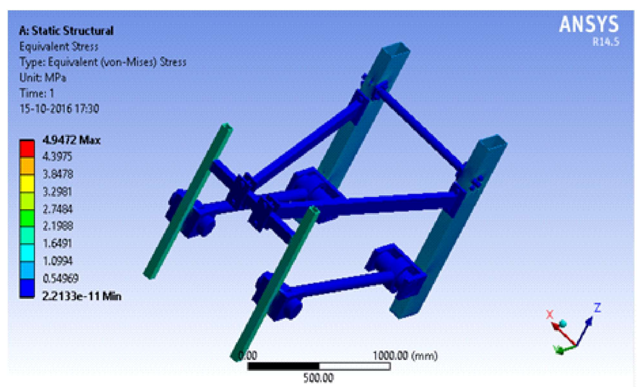

Fig 6. Dynamic analysis of initial structure

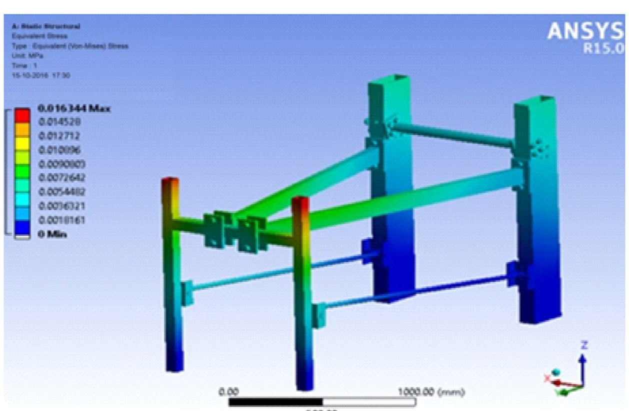

Fig 7. Dynamic analysis of final structure various load conditions

Fig 8. Developed high clearance tractor

2/3rd of the wheel base ahead of the rear wheel axle. The weighing method is used to find the centre of gravity of developed tractor. However, this method does not consider the effect of movement of oil in crankcase, transmission oil and fuel in the partly filled tanks as well as weight and position of operator. So, the following assumptions were made in this method.

- The tractor tyres were rigid and there was no deflection during weighing
- The shift of fluid, coolant, and lubricating oil when tractor was tilted were ignored.

Consider that the tractor has weight W, and wheel base L. The longitudinal and vertical location of its centre of gravity was found out by weighing the front axle of tractor to determine N_F. First the weight on the front wheels of the tractor was taken on the level ground.Referring to free body diagram of forces on level ground, N_r and N_f were the soil reactions against the rear and front wheels respectively.

$$g = N_f x\ L/W \qquad \text{(i)}$$

Thus the location of centre of gravity from rear wheel axle of tractor would be at a distance ‘g’ and can be calculated by using the above equation.

Determination of height of centre of gravity was by elevating the front axle of tractor and geometry of tractor in raised position was used for calculation of centre of gravity of tractor. Again, the front wheels of tractor were lifted by a known height ‘h_1’ which should be adequate to obtain significant difference between reactions N_f andN_f which are measured with the help of weighing scale. The forces acting on the tractor when the front wheels were lifted. Now the location of centre of gravity was calculated by using the geometry of tractor as given below.

$$L' = (L + (d_r - d_f)/ \tan\alpha\ ) \cos\alpha \qquad \text{(ii)}$$

$$\text{Also } \sin\alpha = \frac{h1}{L-\left(\frac{df}{2}\right)\sin\alpha} \qquad \text{(iii)}$$

By using the equation (ii) and (iii), calculate the value of ‘L’ was calculated

Again the taking moments about ‘A’ we get,

$$\text{‘g’} = N'_f x\ L' / w \qquad \text{(iv)}$$

Also from geometry,

$$\tan\alpha = x_2/h_2 = (g - x_1) / h_2 \quad \text{(or)} \qquad \text{(v)}$$

Also, $\cos\alpha = g'/x$ (or) $x = g'/\cos\alpha$

Putting the value of x in equation number (vi),

we get $h2 = (g - g'/\cos\alpha) \tan\alpha$

Now, height of centre of gravity from ground surface ‘h’ was given by $h = d_r / 2 + h_2$

Where,

h = distance of centre of gravity from groun surgacem mm

d_r = diametre of rear wheel of tractor, mm

h_2 = distance of centre of gravity from centre line of rear wheel axle, mm

Critical speed calculation

The geometric configuration of tractors, combined with their ability (aided by individual brakes on the drive wheels) to make sharp turns at moderately high travel speeds, can result in a lateral overturning situation. A tractor in the steady-state condition and take a circular turn. Assuming that the lateral tire forces are sufficient to generate the assumed acceleration, D’Alembert’s principle may be applied by assuming the presence of a force, mv^2/r, acting at the centre of gravity and in a direction opposite to the lateral acceleration of the centre of gravity.

Over turning movement =

Centrifugal force X Centre of gravity height

Stability movement =

Total weight of tractor (W) X Perpendicular distance between the centre of gravity and neutral axis (y)

Therefore,

Overturning movement = stability movement

$$mv^2/r\ .\ h = w\ .y$$

$$wv^2/g\ r\ .\ h = w\ .y$$

$$v = \sqrt{y.g.r/h}$$

v =critical velocity (maximum operating speed)

g = acceleration due to gravity

Reactions of high clearance tractor under dynamic condition

The dynamic weight on tractor axles is required to determine the weight retained on the tractor front axle. Considering force and moments, the dynamic reaction on tractor rear wheel, R_r , and front wheel R_f can be expressed as follows.

Where,

w_t = total weight of the tractor

x = centre of gravity distance from rear axle

l = wheel base

p = pull

y = hitch height

Therefore,

$R_f \cdot l + p.y = w_t.x$ ……………………. (viii)

$R_f \cdot l = w_t \cdot x - p.y$ ……………………......(ix)

$R_f = \frac{Wt.X}{L} - \frac{P.y}{L}$ …………………….(x)

i.e, $R_f + R_r = w_t$ ……………………. (xi)

$R_r = w_t - R_f$ ……………………. (xii)

RESULTS AND DISCUSSION

Dynamic Simulation of Fabricated Structure

The dynamic simulation has been carried out in ANSYS simulation software with assumed normal load of 3000 kg to find the maximum stress and also the maximum load bearing capacity. Initially the developed structure was analyzed in simulation software with equal load distribution on front and rear wheels. It was observed that, the minimum stress and the maximum stress development were 2.21 x 10^{-11} Pa and 4.94 MPa respectively and a uniform stress distribution throughout the structure was observed as shown in Fig 6 and also observed a minor stress concentration on the structure which indicates the excess thickness of structure material. Hence to get stress on the developed structure, thickness of the material was reduced and the above similar simulation procedure was also repeated and observed that, the minimum stress and the maximum stress development were 3.16 x 10^{-10} MPa and 10.84MParespectively.

Dynamic simulation of structure with different normal loads

During actual use of the developed structure, it should bear bending load due to overall weight of tractor as well as weight transfer due to field undulations(dynamic load); hence a similar simulation was carried with different normal loads in simulation software with assumed load of 2000 kg and 1000 kg respectively on each of the front and rear axle.

It was found that, the maximum permissible allowable stress of the extension shaft was 0.016 MPa, whereas the maximum endurance strength of the transducer material was 370 MPa. It was also observed that, the maximum stress at the supporting of the front legs of front axle due to less thickness and contact area of the material. Therefore, the developed structure will be able to sustain under maximum normal loads with heavy shocks. The load conditions of the structure as shown in the Fig 7.

Development of High clearance unit

A small statured tractor of Kubota having 24 hp diesel engine was selected as prime mover for development of high clearance tractor to be used in cotton and other long saturated crops. Selection of small statured tractor as prime mover was mainly due to its lower weight profile and its compactness, moreover produced horse power suffices requirement of intercultural activities. The existing clearance of the tractor was increased with developed high clearance unit using mild steel as a structure. The tractor was lifted up to height of 1.4m using front and rear legs of front axle and rear axle. A frame was developed to support the tractor weight and dynamic loads of the legs were provided for all the wheels for motion. The drive from the tractor rear axle was transferred to the rear wheels using chain and sprocket arrangement for both the rear wheels. The front legs of front wheels and rear legs of rear wheels were connected using horizontal bar for proper supporting and load distribution.

Mild steel channels were used for designing of rear and front wheel legs in the high clearance unit. Depending upon the computed average cotton crop height the length of legs was designed. These four raisers of rear axle and front axle were connected using a square hollow channel frame. The front chassis of the tractor was connected to the developed front axle using angular plates and having width equal to the tractor body.

Spraying and weeding units were developed and attached to the tractor for intercultural operations of cotton crop as well as spraying of chemicals to control the pests and diseases. The tractor has been designed in such a way that, it can be used for multiple operations simultaneously. A provision was made in such a way that, the depth of weeding could be adjusted by engaging the weeding unit lever. The developed high clearance tractor was as shown in Fig 8.

Tractor dynamic analysis

The dynamic analysis of developed high clearance tractor was carried out to find its stability during various operation conditions. The center of gravity of test tractor was measured using weighing method and found that, the center of gravity was located at 1.9 m from the ground surface and 0.76 m from the rear axle of tractor. To find the lateral stability of the tractor during turnings, the critical speed of the test tractor was calculated by considering centrifugal force, weight of tractor and track width of tractor. It was observed that, the maximum operating speed of the tractor during turning is about 2.55 m/s. It is clearly indicated that, if the operating speed of tractor increase 2.55 m/s during turnings the tractor lost the lateral stability.

The dynamic reactions of the tractor front and rear wheel reactions were also measured to find the linear stability of tractor at maximum draft force of the implement. It was observed that, the front and rear wheel reactions are about 208.5 and 796.5 kg respectively. It was also observed that, the maximum weight transfer from the tractor front axle to rear axle was about 126 kg. Based on the recommendations of Harbata1971 (Mehta, 2014), to achieve longitudinal stability and maneuverability of the tractor, the weight on front axle was not less than 20 % of weight on front axle during static condition.

CONCLUSION

The dynamic simulation has been carried out in ANSYS simulation software with assumed normal load of 3000 kg to find the maximum stress and also the maximum load bearing capacity. It concluded that, the developed high clearance tractor was in stable condition even after calculation of all analysis. It was found that the location of centre of gravity of tractor is1.9 m from the ground surface. The critical speed of tractor is 2.55 m/s and the front and rear wheel reactions are about 208.5 and 796.5 kg respectively at maximum depth of operation.

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