An electromechanical implement lift system with position control for low horse power tractor

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Abstract: Based on the output of software made in Visual Basic, an electromechanical implement lift system with position control was developed to maximize useful power of a low horse power (hp) tractor by replacing hydraulic system requiring higher power. It comprised of two lower links, one top link, two lift rods, one connecting rod and a power screw mechanism. The prototype was tested as per IS: 12224-1987 for recommended load of 150 kg on test frame and satisfactory results were found. The response time for lifting a load of maximum lifting capacity on test frame i.e. 116 kg and 110 kg for entire lifting range was found to be 71 s and 20.7 s for single start screw and triple start screw, respectively as compared to 44.7 s and 13.3 s for lowering the loads. The position control of the system was also tested and found satisfactory with no drop in the height for maximum lifting capacity. The developed system could save 88% of tractor input power compared to hydraulic system.

Highlights

- Design of an electromechanical implement lift system for low hp tractor.
- Provision of position control system.
- A single operator's switch could operate the system and preset the depth.
- Saving of tractor input power by 88 % compare to hydraulic system.

Keywords: Implement lift system, Electromechanical, Position control, ACME screw and nut, Visual Basic.

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1 Introduction

The mounted type hitch is beneficial for low hp tractors as it has greater manoeuvrability of the tractor and implement combination. It is more compact and closer to the tractor with better transport characteristics. It also reduces cost of the implement by eliminating the extra depth control wheel in the implement and increases dynamic loading of tractor drive wheels (Morling, 1979). From commercial test reports, test results (Anon. 2004) it was also observed that power requirement for hydraulic three point linkage operation do not increase linearly with increase in horse power of tractors. It is varying as 21%, 23%, 16.5%, 14.8% and 17.3% for tractors up to 10 hp, 10 to 20 hp, 30 to 40 hp, 40 to50 hp and 50 to 60hp, respectively (Anon., 1999; Anon., 2001; Anon., 2003; Anon., 2007; Anon., 2009; Anon. 2010; Anon., 2013). Percentage of power consumed for actuating the hydraulic system of low hp tractor is more as compared to that for higher hp tractor which leads to less useful power available at drawbar and PTO (Power Take Off) for various agricultural operations and hence reduces its applicability.

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With the increasing trend to use lower hp tractors to improve mechanization level in India replacing hydraulic system in low hp tractors by some alternative system with same functions can be a better choice to improve useful power by providing more input power to the axle. Mechanical or Electromechanical systems are the two main alternatives to hydraulic system. Mechanical system requires more effort to operate and it cannot be easily fitted with position control while electromechanical system with position control may work effectively.

2 Materials and methods

The proposed implement lift system which is different from conventional three point linkage consists of two lower links, one top link, lift rods, connecting rod, power screw mechanism (Single and triple start) to be fitted to a frame with a gear and pinion and a PMDC (Permanent Magnet Direct Control) motor. This motor is powered by tractor battery (12V, 50Ah). An operator's switch i.e., DPDT (Double Pole Double Throw) will be used to change the polarity of the motor so as to change its rotational direction. The detail design calculations for deciding the dimensions of links, screw size, capacity of motor are made in the following section:

2.1 Design of implement lift system

2.1.1 Design of three point linkage

The design of each component of three point linkage was done based on maximum forces experienced for two main cases i.e. first for working with a matching size cultivator and second one was for lifting a recommended load on standard frame.

2.1.1.1 Prediction of draft

The draft of the matching size cultivator was determined based on following ASAE draft Equation,

$$D = F_j [A + Bv + Cv^2] Wd \quad (1)$$

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 = Actual speed, (km/h); W = Number of rows or tools; d = Tillage depth, (cm).

2.1.1.2 Forces acting on three point linkage while working with cultivator

Forces acting on three point linkage and implement are

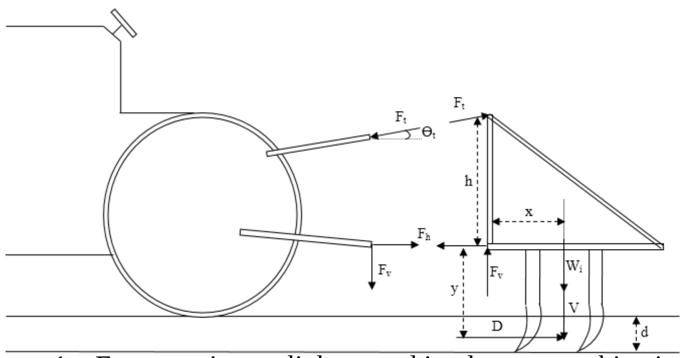

Figure 1 – Forces acting on linkage and implement combination

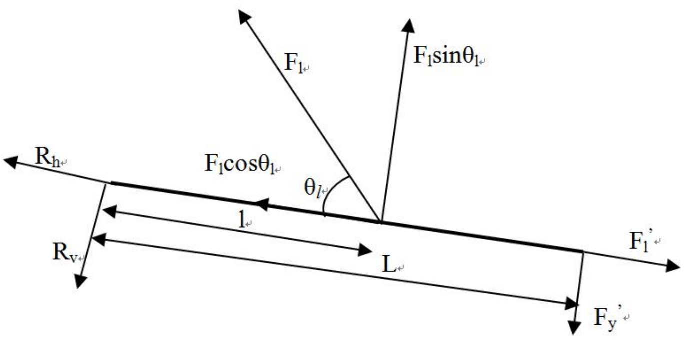

Figure 2 – Forces on lower link and lift rod

shown in Figure 1. The forces acting on lower links are further resolved into inline and perpendicular to the lower links and these inline forces are shown in Figure 2.

From Figures 1 and 2, forces acting on the links can be calculated by using following Equations,

$$F_t = \frac{Dy - (W_i + V)x}{h\cos\theta_t} \quad (2)$$

$$F_h = D\left(1 + \frac{y}{h}\right) - \frac{(W_i + V)x}{h} \quad (3)$$

$$F_h = F_t\cos\theta_t + D \quad (4)$$

$$F_v = W_i + V - F_t\sin\theta_t \quad (5)$$

$$F_l' = \frac{F_h'\cos\theta_h + F_v'\sin\theta_h}{\cos\theta_v} \quad (6)$$

$$F_y' = \frac{F_v'\cos\theta_h - F_h'\sin\theta_h}{\cos\theta_v} \quad (7)$$

$$F_l = \frac{F_y' L}{l\sin\theta_l} \quad (8)$$

Where, h = Mast height; y = Centre of resistance of cultivator from lower hitch point in vertical plane; x = Centre of resistance of cultivator from lower hitch point in horizontal plane; F_t = Top link force; F_h = Force in lower link in horizontal direction along the direction of motion; F_v = Vertical force on lower link; Θ_t = Angle of top link with horizontal; Θ_v = Angle of lower link with direction of motion in horizontal plane; Θ_h= Angle of lower link with horizontal; F_h' = Compressive force in each lower link; F_v' = Bending force in each lower link; F_l = Force in the lift rod; θ_l = Angle of lift rod from lower link.

2.1.1.3 Forces acting on the links of three point linkage while lifting a specified load

Forces on each linkage were checked while working with implement and also while lifting a specified load on standard frame. Figure 3 shows forces acting on links while lifting a specified load.

Let W_i be the lift capacity of tractor at 610 mm away from hitch point. Forces on each linkage were first calculated by using following Equations,

$$F_t = \frac{1.67x\, W_i}{\cos\theta_t} \quad (9)$$

$$F_v = W_i + F_t\sin\theta_t \quad (10)$$

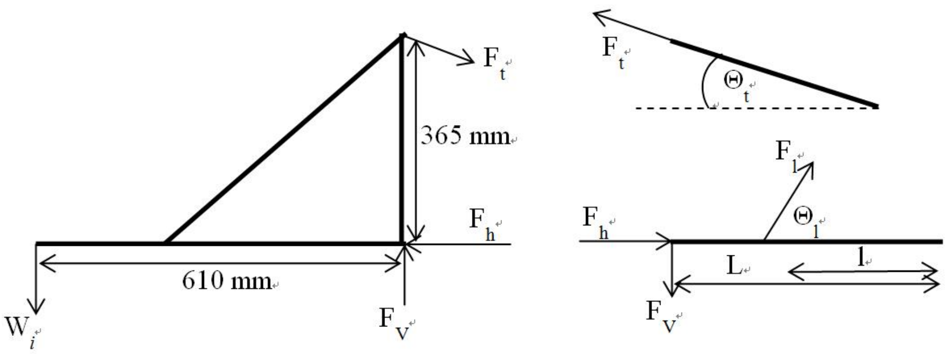

Figure 3 – Forces in linkages while lifting a specified load

$$F_h = F_t\cos\theta_t \quad (11)$$

$$F_l = \frac{F_v L}{l\sin\theta_l} \quad (12)$$

Based on these two conditions, maximum force was considered for designing three point linkages.

2.1.2 Design of power screw mechanism

Power screw mechanism consisted of ACME screw, ACME nut, support rod, gear and pinion and PMDC motor. The power screw mechanism was designed based on maximum load experienced by it and this maximum load is shown in Figure 4 and given by Equations 13 and 14.

Load on power screw while lifting,

$$W = F_l\cos\Theta_c + \mu F_l\sin\Theta_c \quad (13)$$

Load on power screw while lowering,

$$W' = F_l\cos\Theta_c - \mu F_l\sin\Theta_c \quad (14)$$

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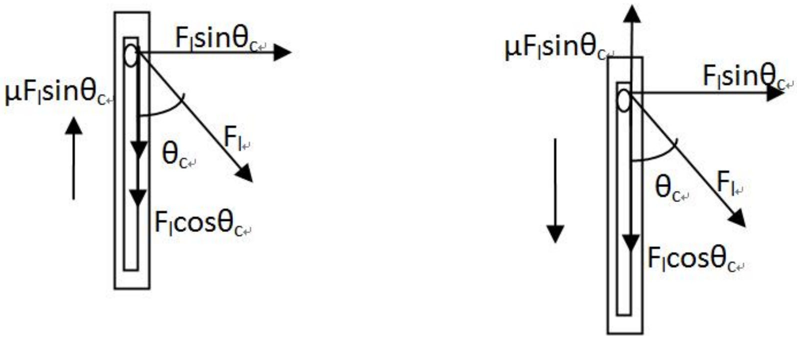


(a) Lifting (b) Lowering

Figure 4 – Forces acting on power screw mechanism

The power screw and nut were subjected to compressive and torsional stresses hence design was done by using following Equation;

$$\tau_{max} = \frac{1}{2}\sqrt{\sigma_c^2 + 4\tau_T^2} \quad (15)$$

Where, μ = coefficient of friction between the screw and nut; μ = tanΦ; Where, Φ = friction angle; Θ_c = angle of lift rod in vertical plane. τ_{max} = design or working stress; τ_T = torsional shear stress at the outer surface of screw; σ_c = compressive stress.

2.1.3 Selection of PMDC motor

The PMDC motor was selected based on maximum torque requirement of the power screw which included torque requirement for lifting the load and torque to overcome the frictional losses in bearings.

Torque requirement for lifting the load,

$$T_{su} = \frac{W'd_m}{2}\tan(\emptyset + \alpha) \quad (16)$$

Torque requirement for lowering the load,

$$T_{sd} = \frac{W'd_m}{2}\tan(\emptyset - \alpha) \quad (17)$$

$$\tan\alpha = \frac{L}{\pi d_m}$$

$$\tan\emptyset = \mu'$$

For ACME thread, virtual friction coefficient, μ' = μ/cosΘ

Where, W = load on screw while lifting; d_m = mean diameter of the screw; α = helix angle of the screw; $\emptyset$ = angle of friction; Θ = semi-angle of thread; L = zp = lead of the screw; Where, z = number of start of thread.

Torque requirement for ball bearing,

$$T_B = \frac{2}{3}\mu W R \quad (18)$$

Torque requirement for thrust bearing,

$$T_T = \frac{2}{3}\mu W R_m \quad (19)$$

Where, T_B = Torque required for ball bearing; μ = coefficient of friction in bearing; W = weight on the bearing; R = radius of the shaft; R_m = mean diameter of the bearing.

The power requirement of the motor was calculated based on following Equation;

$$P_m = \frac{2\pi NT}{60\,\eta_m} \quad (20)$$

Where, P_m = power requirement of the motor; T = maximum torque requirement; N = rpm of the screw; η_m = efficiency of the motor.

A program was written in Visual Basic to carry out these computations for determining the forces acting on the links, designing the power screw mechanism and deciding the torque and power requirement of motor. The flow chart for this is given in Figure 5.

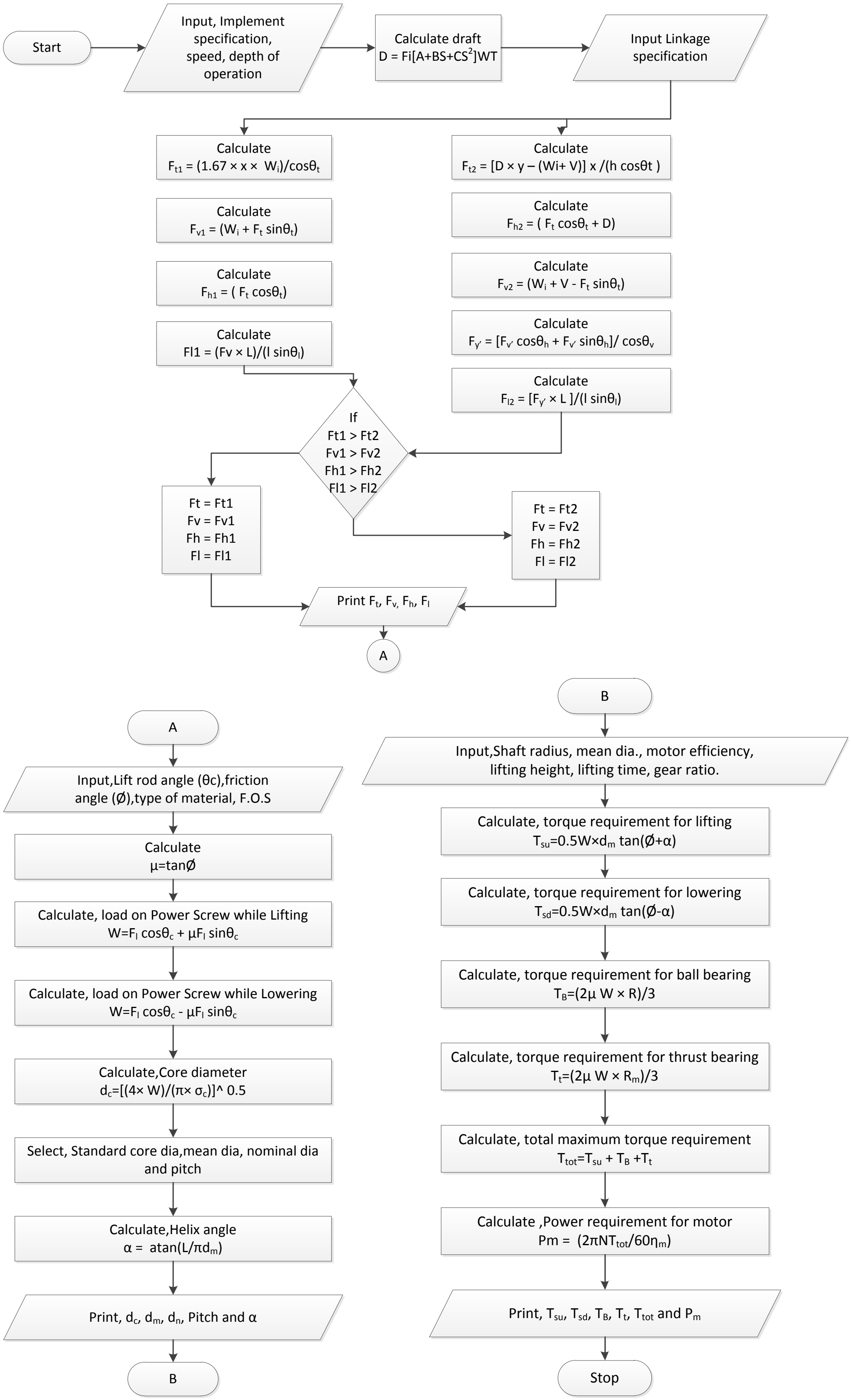
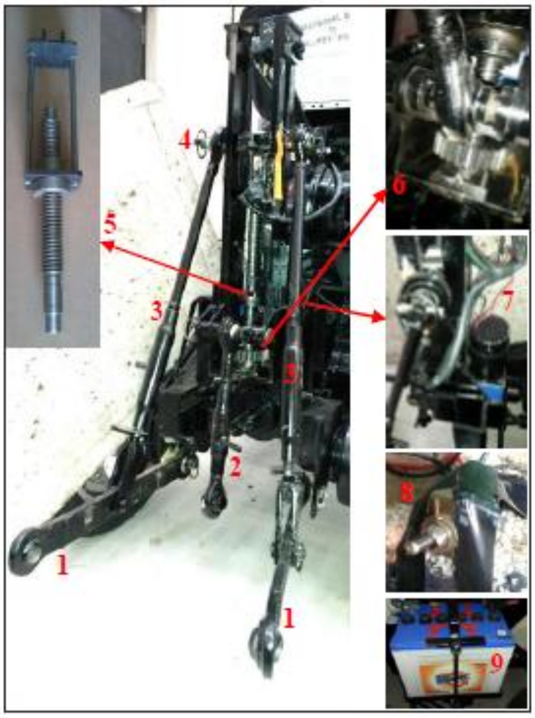


Figure 5 – Flow chart for computing forces acting on the links, designing the power screw mechanism and deciding the torque and power requirement of motor

2.2 Electromechanical implement lift system

The developed implement lift system designed on the basis of the output of the software is shown in Figure.6. It is different from conventional three point linkage and consisted of two lower links, one top link, lift rods, connecting rod, power screw mechanism (Single and triple start) fitted to a frame with a gear and pinion and a PMDC (Permanent Magnet Direct Control) motor. This motor was powered by tractor battery (12V, 50Ah). An operator's switch i.e., DPDT (Double Pole Double Throw) was used to change the polarity of the motor so as to change its rotational direction and hence to facilitate both lifting and lowering. One of the important parameter for three point linkage is position control of the system which is required to achieve any desired position of the implement during working and transportation of the implement. This electromechanical system is fitted with a self-locking screw and electric limit switches to raise or lower the implement within the range. The coefficient of friction of the screw and nut is more than the helix angle of the screw which makes it self-locking. For setting desired depth of operation, operator has to set the position of a limit switch on a position control gauge before starting the operation which restricts the lowering of the implement.



1. Lower link; 2. Top link; 3. Lift rod; 4. Connecting rod; 5. Screw mechanism; 6. Gear and pinion; 7. PMDC motor; 8. DPDT switch; 9. Battery.

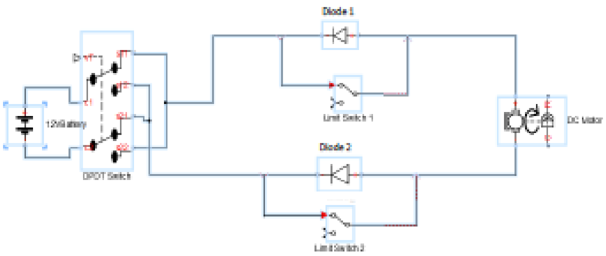
Figure 6 – Electromechanical implement lift system

The PMDC geared motor was in mesh with the power screw with a gear and pinion arrangement which was operated by a 12 V battery. The operator had to operate an ON-OFF-ON DPDT switch. When switch was lifted up, the motor rotated clockwise and the screw mechanism lifted the implement similarly when it was lowered down condition, the implement came down and when the switch was in off mode (Neutral position), the implement was fixed at that position due to self-locking of the screw mechanism.

2.3 Position control of the system

The lifting and lowering of the implement were done by using a DPDT switch. The position control was made by using an electric circuit which is shown in Figure 7. In this mechanism, a DPDT switch was used to change the polarity of the PMDC motor to change the rotation of the motor. It had two limit switches which restricted the motion of the motor when the desired height of the implement was achieved. A limit switch (LS1) was fixed at the top of the frame which was operated by top support bracket. When the implement reached the maximum height this switch made the circuit open hence stopped the motor rotating in the clockwise direction. This switch also acted as safety switch by preventing further lifting of the implement once it reached maximum lift height.

Another limit switch (LS2) was placed at the lower end of the frame which was moved based on the desired depth of operation on a position control gauge which was bolted on the frame against a calibrated scale of height from the ground. This switch was also operated by top support bracket and opened the circuit when the implement reached at the lowest position. Hence, the desired position was achieved.



(a) Electric Circuit

(b) Position control system

1. Limit switch-1; 2. Limit switch-2; 3. Top support bracket; 4. Position control gauge.

Figure 7 – Electric circuit for position control

3. Test procedure

Lifting capacity and response time of the developed electromechanical implement lift system were tested under laboratory conditions from January 2014 to February 2014 as per IS: 12224-1987. A test frame was attached in the three point linkage and then various known loads were applied. The response time for lifting and lowering was measured by using a stop watch. The maximum lift capacity of the system was measured by gradually applying load on the test frame. When motor got stopped at a particular load at different positions of the system, that load was considered as maximum lifting load at that particular position. The maximum load which was lifted by the system without stopping the motor was considered as maximum lift capacity of the system. Lifting capacity test was also done for applying load on lower links by attaching a drawbar on both the lower links.

Position control of the system was checked by applying load of the maximum lifting capacity on test frame and lifted to the maximum lifting height and then the height of the lower hitch point from the ground was measured at 5 min interval for 30 min.

4. Results and discussion

An electromechanical implement lift system with a position control was developed. The system was operated by a 12 V, 0.25 hp PMDC motor.

4.1 Lifting capacity of the System

Lifting capacity of the electromechanical implement lift system was tested with single start and triple start screw. The test results are given in the Table 1.

Table 1 – Lifting capacity of the developed system

Position	Lifting capacity, kg			
	Standard frame		Lower hitch point	
	Single start screw	Triple start screw	Single start screw	Triple start screw
At horizontal condition	155	146	202	194
At lowest hitch point (175 mm from ground)	143	138	172	165
At maximum lift condition (340 mm above the lowest hitch point)	116	110	148	139

From Table 1, it can be observed that the lifting capacity of the developed electromechanical implement lift system was found to be 155 kg and 146 kg on standard frame for single and triple start screw, respectively. The maximum lifting capacity of single start screw was higher than that of triple start screw. This could be due to higher torque requirement for triple start screw. The developed electromechanical implement lift system was capable to lift a load of 116 kg and 110 kg to a maximum lifting height of 340 mm from the lower hitch point (which was 175 mm from the ground) for single and triple start screw, respectively. The highest lifting capacity at the lowest hitch point and at horizontal condition was found to be 143 kg, 138 kg; 155 kg, 146 kg for single start screw and triple start screw, respectively.

The maximum lifting capacity at lower hitch point was 148 kg and 139 kg to a maximum lifting height of 340 mm from the lower hitch point for single and triple start screw, respectively. The highest lifting capacity at the lowest hitch point and at horizontal condition at lower hitch point was found to be 172 kg, 165 kg; 202 kg, 194 kg for single and triple start screw, respectively.

4.2 Response time of the system

The response time of the system was measured at different loads on test frame for both single and triple start screw by using a stop watch and the results are shown in Figures 8 and 9 for single and triple start screw, respectively.

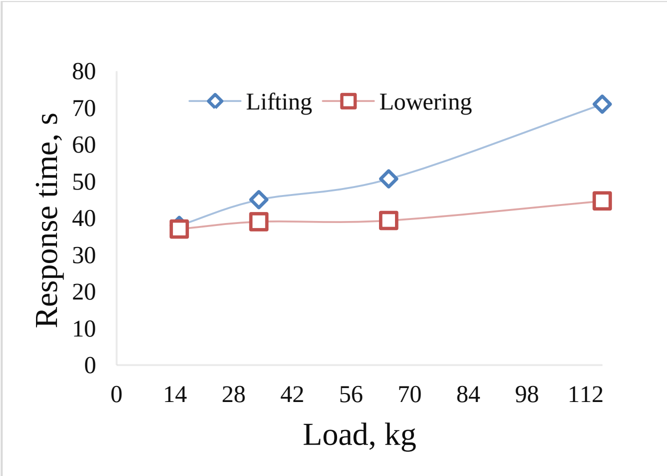


Figure 8 – Response time for single start screw for load on test frame

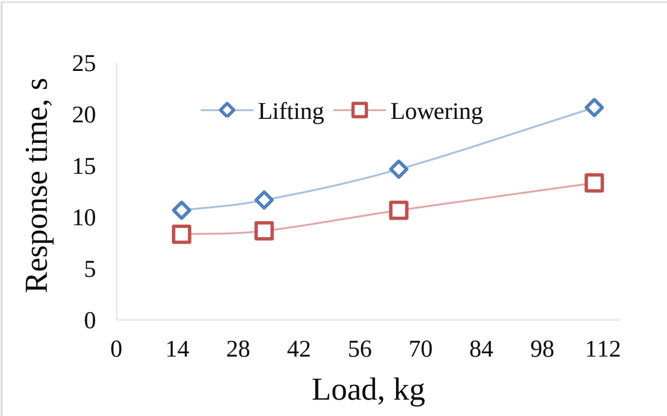


Figure 9 – Response time for triple start screw for load on test frame

Response time for lifting and lowering the load of 116 kg on test frame for single start screw was found to be 71 s and 44.7 s, respectively as compared to 20.7 s and 13.3 s for a triple start screw with a load of 110 kg.

4.3 Position control of the system

There was no drop in the height of the implement with the developed implement lift system hence exact position of the implement could be maintained.

5 Conclusion

Based on the results of the study, following specific conclusions are drawn;

1. Minimum and maximum lifting height of the developed electromechanical implement lift system was 175 mm and 515 mm, respectively and it was found closer to category – 1N hitch system.
2. The lifting capacity of the developed electromechanical implement lift system with a single start screw was found to be 155 kg and 202 kg at horizontal condition on test frame and lower links, respectively, as compared to 116 kg and 148 kg at the maximum lifting height.
3. The lifting capacity was also measured for a triple start screw which was 146 kg and 194 kg on test frame and lower links, respectively, as compared to 110 kg and 139 kg at the maximum lifting height.
4. The response time for single start screw for lifting 116 kg load was measured as 71 and 44.7 s for lifting and lowering, respectively, as compared to 20.7 s and 13.3 s for lifting 110 kg with a triple start screw.
5. The electric position control system worked effectively and the desired depth of operation could be set before operation.
6. There was no drop in the height of the load with maximum lifting capacity at maximum lifting height observed for 30 min, hence designed electromechanical system is more reliable.
7. The developed electromechanical implement lift system can save 88% of tractor input power compared to hydraulic system.

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