Journal of Animal and Veterinary Advances 9 (6): 1005-1010, 2010
ISSN: 1680-5593

A Cost Effective Forklift for Materials Handling in Animal Production

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Abstract: The objective of this study was to dimension, construct and determine the operational characteristics of a forklift to be used in materials handling in animal production and in other agricultural operations. A forklift with a load capacity of 600 kg was constructed, consisting of a single mast, single acting lift cylinder and a double acting tilt cylinder, to be mounted on a standard agricultural tractor. The minimum lift height is 1500 mm using the mast, whereas the maximum height is 2020 mm when the forklift is raised through the lifting arms of the three-point hitch of the tractor. Piston and fork speeds during lifting are 0.065 and 0.13 m sec^{-1}, respectively, while the lowering speeds are 0.11 and 0.22 m sec^{-1}. Lifting takes about 10-12 sec, while lowering takes about 6-8 sec. Static stability was maintained during tests at inclined concrete surfaces at the maximum capacity of 600 kg at vertical position of the mast. Assuming that most agricultural materials will be handled with loads less 600 kg, the tractor (New Holland 60-56) forklift combination can operate safely both on horizontal and inclined road conditions without causing static or dynamic instability. The capacity of the system is about 10-11 tons h^{-1} with loads of 200 kg at 50 m travel distance.

Key words: New Holland 60-56, forklift, stability, capacity, material handling

INTRODUCTION

Tractor-implement systems are of utmost importance, since the efficiency of agricultural operations is highly related with the tools powered by the tractor. There have been many functional improvements in tractors due to various types of operations needed in agriculture. Technical improvements and cost-effective operations of tractor-implement systems broadened the use of tractors and agricultural equipment throughout the world. As a consequence of wide-scale use of tractors and related implements, numerous benefits were brougth to agriculture (Alcock, 1986). Tractors and mechanization increases productivity, changes the nature of farm work by making, it less exhaustive and attractive as well (Liljedahl *et al*., 1996).

Human, however is not designed perfectly to be a power source and as a power source is limited to <0.1 kW continuous power output. Thus human should not function as the primary source of power but should be controlling the power to increase the efficiency (Liljedahl *et al*., 1996). Nevertheless, farm work including loading, unloading and transporting to short distances are still heavily dependent on labor in small and mid-size farms in the developing world.

One of the most importand features of an agricultural tractor is the hydraulic power available to drive equipment attached to the tractor. Front loaders, skreypers and forklifts have found their places in agriculture for transporting agricultural products, such as granular materials, bales, feeds in sacks, fruit or vegetable boxes. A cost-effective, light-weight forklift that can be attachted to the three point hitch could be preferred and used efficiently by smaller farmers. Such a tractor-forklift system is needed to transport relatively small loads frequently encountered in farms to reduce the number of workers in fruit orchards and vineyards or during bale loading to trailers.

Efficiency can be increased in loading, lifting, transporting and stowing in all agricultural operations. Such operations particularly include loading and carrying bales, feed materials in bags in animal production and fruit and vegetable containers in horticultural harvest operations Forklift equipment can be used to handle pallet sized loads, which can be desirable during on-farm operations (Srivastava *et al*., 1994). The use of such equipment increases the total work hours of a tractor in a year, resulting in a decrease in costs of a tractor per hour and in more profitable machine operations (Hunt, 1995). Larger machines can complete the required work quickly, but when the timeliness is not taken into account, the smallest machines would be more economical due to low fixed and variable costs associated with small equipment (Srivastava *et al*., 1994).

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The objectives of this study were to construct a cost-effective forklift of 600 kg load capacity with a single mast and to determine the operational characteristics of the forklift that can be attached to the hitch of New Holland 60-56 agricultural tractor. The forklift was designed in its simplest form so that it can be affordable by small farmers.

MATERIALS AND METHODS

Dimensions of New Holland 60-56 agricultural tractor used in this study are shown in Fig. 1 and some technical properties are shown in Table 1.

Hydraulic power and lift test results for the three point hitch were taken from the tractor test reports. Hydraulic oil flow rate requirement was 17 L min^{-1} to raise the lift cylinder of the forklift at a speed of 0.1 m sec^{-1}. The pump flow rate and the corresponding pressure are sufficient to provide 600 kg lifting capacity.

Mechanical system: Mechanical system consists of a single mast to avoid lessen the cost of the forklift for the small farmer. The mechanical system comprised the forks, fork carrier, mast, lift chains and rollers (Fig. 2). The forklift was mounted on the three point hitch of the tractor.

Lifting capacity of the forklift depends on the load center. ISO 2328 and 2329 were used to determine the dimensions of the forks. According to the standard, load center should be 400 mm for loads up to 1 ton but may vary depending on the application, load and material selection. In this study, load center was chosen to be 525 mm.

The mast was made of 10 mm thick steel sheets (U profiles), sufficient to support a load up to 1 ton. Fork carrier moves in the U profile over roller bearings. Lift chains are supported by two rollers driven by the movement of the lift cylinder up and down. Design of individual machine elements, including rolling bearings, lift chains and sprockets, the mast and carrier was based on mechanical design and material selection principles (Childs, 2004; Ashby, 2007).

Hydraulic system: Two alternatives were considered for the hydraulic system in the study. First, a single acting lift cylinder was used and the tilt cylinder was not included in the system. In this system, there was no need for any supplemental hydraulic component but a hose to connect the quick coupling of the tractor to the lift cylinder. The cylinder is operated by the hydraulic lever of the tractor, which does not necessitate a directional control valve.

The second system included a double acting tilt cylinder in addition to the lift cylinder in the hydraulic system, along with the directional valves for both cylinders and pressure relief valve.

Stability: Center of gravity and stability of a tractor-forklift system may be affected by many factors. Center of gravity keeps changing its position as the mast is tilted and when the tractor travels on different slopes or while

Table 1: Dimensions and technical properties of New Holland 60-56

Dimension (mm)	Values	Property	Values
R(s)	640	Front track width (mm)	1450-1850
A	1705	Rear track width (mm)	1430-1930
B	2052	Minimum toprak aralığı (mm)	355
C	3565	Front axle load (kg)	735 (operator included)
D	2345	Rear axle load (kg)	1401
E	2470		
H	470		
F (front)	1450		
G (back)	1435		

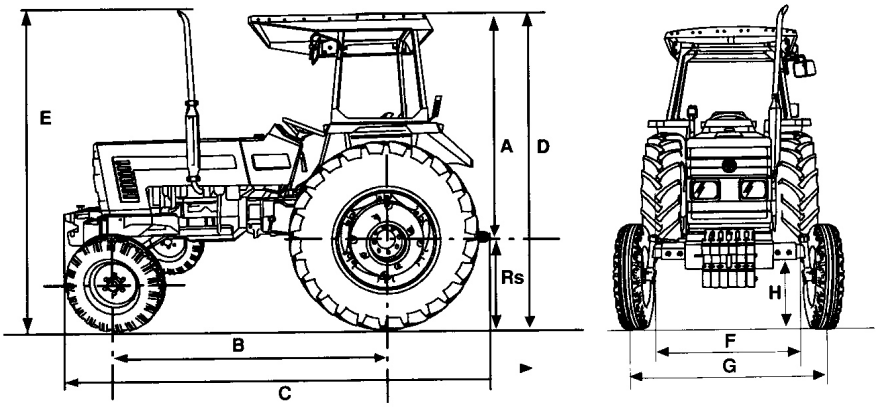

Fig. 1: General dimensions of New Holland 60-56 agricultural tractor

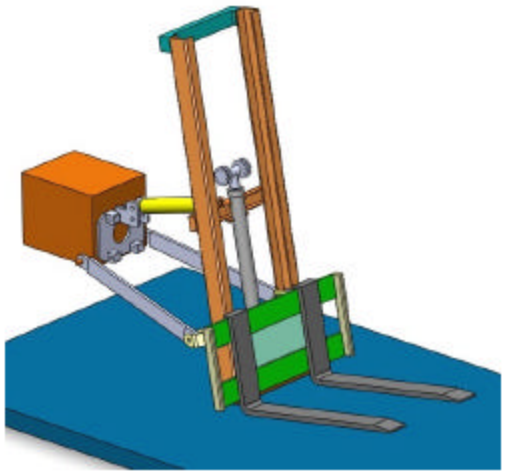

Fig. 2: Forklift without the tilt cylinder

the load is being lifted and lowered. In this study, the following experiments were conducted to asses the static and dynamic stability of the system:

Static tests: Stability tests on flat surface and 2.5, 6.5 and 11.0° inclined concrete road with different loads (200, 300, 400, 500 and 600 kg) at varying load centers (400, 500, 600, 700 and 800 mm).

Dynamic tests: Stability tests on flat surface and on 2.5 and 6.5° inclined concrete road with different loads (100, 200, 300, 400, 500 and 600 kg) to observe the effect of sudden stops and take-offs.

Time consumption: Time consumption was measured to load, transport and unload various loads (100, 200 and 600 kg) over a distance of 50 m on a flat concrete with three replicates. Lifting and lowering times for empty and loaded forks were measured and the corresponding hydraulic piston speeds were calculated.

RESULTS AND DISCUSSION

Dimensions and operational features: Physical dimensions of the forklift are given in Table 2. Mast height is 1950 mm which is close to mast height of the industrial forklifts. The lift height at tractor lift arms lowered position (1500 mm) is limited due to the single mast system. A taller mast could be designed to obtain greater lifting heights, which may be more functional for some farm operations. Although, the lift height is limited with a single mast system, it is possible to stack various shaped agricultural materials to trailers and trucks commonly used for transportation. The single mast forklift

Table 2: Physical dimensions of the tractor forklift-system with tilt cylinder mounted on

Property	Values
Lift height (mm)	2020 (lift arms fully raised)
	1500 (lift arms lowered)
Free lift height (mm)	0
Fork size (length, width, thickness (mm)	1050 × 100 × 32
Mast tilt angle (degrees)	8°/20° (lift arms fully raised)
	12°/22° (lift arm lowered)
Overall width (mm)	1000 (carrier)
	560 (mast)
Mast lowered height (mm)	1950

designed for the tractor eliminated longer lift chains, longer mast and additional relevant rollers that need to be used on dublex mast system. For transporting heavier materials and stacking to greater heights, more costly and heavier solutions should be sought.

The load should be tilted rearward for transporting the loads on flat terraines and the tilt angle should be increased, when the tractor travels on upwards slopes. When a tilt cylinder is not incorporated into the system, the lift arms of the tractor should be used to raise the forklift to accomplish a safe tilt angle, which coprresponds to about 150-200 mm lifting of the mast from the ground level.

The maximum tilt angle using the lift arms to fully raise the forklift was found to be 12° without the tilt cylinder and 20° with the tilt cylinder. At the maximum tilt angle, the mast height is 2520 mm while the clearance from the ground is 570 mm. Since, the loading and unloading should be done with no or small tilt angles, the stacking height is limited without a tilt cylinder and the tractor lift arms will not be functional to increase the lifting height but are useful for carrying the load safely on inclined terrains. A tilt cylinder allows the operator to fully raise the lift arms and then adjust the tilt of the mass as needed. Therefore, the lift height can be increased to 2020 mm with a tilt cylinder.

Mechanical system

Maximum allowable load: New Holland 60-56 has a mass of 2161 kg and maximum allowable load is 4350 kg. The dead mass of the forklift is 290 kg, maximum load to be carried is 600 kg, the mass of a pallet is about 20 kg and the mass of the operator is 80 kg, resulting in a total mass of 3151 kg. The total mass of the tractor-forklift combination is less than the maximum allowable load of the tractor.

Lifting and lowering speeds: Lifting time varies between 11 and 13 sec, respectively for empty forks and 600 kg load capacity (Table 3). Forklift can be easily operated at the idle speed of the tractor engine. The lifting speed, however can be inceased by increasing the oil flow rate.

Table 3: Lifting and lowering durations (sec) of different loads at idle engine speed-static test

	Lifting		Lowering	
Load (kg)	Average	SD	Average	SD
0	10.89	0.18	8.44	0.20
100	11.41	0.16	7.13	0.77
200	11.75	0.27	6.89	0.45
400	11.96	0.05	7.54	0.20
600	12.92	0.14	6.80	0.64

The lifting speed was measured to be 5 and 2.5 sec at medium engine speed and maximum engine speed, respectively. Higher lifting speeds may be preferred for stacking small weights to increase the hourly capacity of the operation.

Fankhauser and Schiess designed a forklift for an agricultural tractor and suggested that the lowering duration should be about 10 sec. The lowering speed at higher capacities is faster and should be controlled by using the hydraulic lever of the tractor to control the lift cylinder. According to the observations during the experiments, lowering the load in <7 sec created difficulties in controlling the system and resulted in less stability during a sudden stop. This is especially true for operating on slopes. The lowering can be done slowly and hence better control can be accomplished when the operator gets familiar with the system.

Based on the lifting and lowering times and the piston stroke, the lift speed and lowering speeds of the forklift were calculated (Table 4). Lift speed is twice the piston speed, whereas the lifting height is twice the length of the piston stroke. Average lift speed decreases with increasing load and varied from about 0.07-0.06 m sec^{-1}, while the lowering speed increases with increasing load and varied from about 0.18-0.22 m sec^{-1}. The lowering speed was not proportional to load because the operator attempted to control the speed and was not sufficiently consistent in controlling the lowering speed. This will probably not observed as the operator gets acquinted with the system.

Stability of tractor-forklift system: Front axle load of the tractor is 735 kg, corresponding to 34% of the total mass of the tractor. Static or dynamic load distribution changes as the forklift is mounted on the rear of the tractor. Front and rear axle loads were not measured under different loads and working conditions in this study. No stability problems were observed on flat surface up to maximum loading capacity (600 kg). The load center of the forks is 525 mm, however, the tests were conducted with greater load centers as well. During the static tests on inclined roads, there were cases, where front load was not sufficient for steering. A load of 600 kg can be raised up to maximum height on 6.5° slope at 600 mm load center

Table 4: Piston and fork speeds at idle engine speed (m sec^{-1}) static test

	Lifting		Lowering	
Load (kg)	Piston speed	Lift speed	Piston speed	Lowering speed
0	0.069	0.138	0.089	0.178
100	0.066	0.132	0.105	0.210
200	0.064	0.128	0.109	0.218
400	0.063	0.126	0.099	0.198
600	0.058	0.116	0.011	0.220

whereas static stability was lost as 600 kg load was placed at a load center of 700 mm. Front axle load should be about 200 kg to maintain steering ability of the tractor. Since, the tractor should move slowly at the maximum height either to stack or unload materials from a stack, greater front axle load will be required under for dynamic operating conditions.

Static stability tests on 11.0° slope demonstrated that 500 kg can be safely raised at 400 mm load center wherease the stability could be maintained only up to 350 mm height at load center of 550 mm with the maximum loading capacity.

Based on these tests, it was concluded that the forklift can be operated safely on flat terrains and small slopes with the maximum load at the designed load center of 525 mm. If the load center must be increased due to the working conditions, the total load to be raised to maximum lift height should be decreased.

About 600-2200 kg capacity forklifts are in use and that 200 kg load is required at the front axle for practical purposes, which assures the maneuverability of the tractor-implement system. In this study, 120 kg front weight was used and no stability problems were observed. The potential instabilities can be overcome by using more front weight as the the slope and load center are to be increased.

Dynamic tests were conducted to draw general conclusions on the stability of the tractor-forklift system. The tractor can travel safely with the maximum load on 6.5° slope provided that the forks are close to road during transportation. Front weight was not sufficient during backward travel with 600 kg load, 550 mm load center and 6.5° slope and stability was difficult to maintain sudden stops.

Hydraulic system: The single acting hydraulic lift cylinder was operated by using the hydraulic lever of the tractor in the case that did not have a tilt cylinder. Consequenlty, no additional hydraulic system element was needed in the system except for a hydraulic hose. The lowering is done by the self weight of the forks and the carrier unless the forks are loaded with the material to be transported. Hydraulic lever can also be used to control the lowering speed, which eliminates the need for a directional valve or a flow control valve.

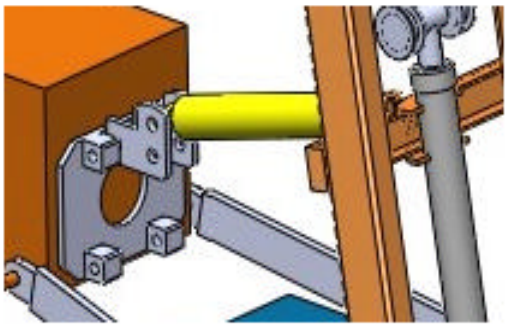

Fig. 3: L shaped support plate for connecting the top link/tilt cylinder to the chaises of the tractor

According to tractor test reports, capacity of the lift arms at 18 MPa is 11.74-12.92 kN depending on the lifting height. Considering the forklift self mass (290 kg), maximum load capacity (600 kg) and pallet mass (20 kg), approximately 8.7 kN is required to lift the forklift. This suggests that the forklift can be easily raised and lowered by the tractor lift arms.

Since, tractors usually operate on rough terrains, high vibrotary forces may act on the tractor through the top link of the three-point hitch when the forklift is to be used on rough surfaces over prolonges working hours. The reaction forces on the top link, however, may be directed to the chaises of the tractor rather than the hydraulics through the leaf spring on which the top link is mounted. An L shaped support plate was added to the mechanical system to which the top link (or the tilt cylinder) was mounted to eliminate the forces that are transferred to the hydraulic system of the tractor to eliminate continual forces on tractor hydraulic sensing system (Fig. 3). This could be an important issue especially for forklifts of high load capacity.

When a tilt cylinder is added to the system, two directional control valves and a pressure control valve were also incorporated into the system and the valve block was mounted on the chassis over the right rear tire of the tractor. Tractor oil flow rate was sufficient to operate both the lift cylinder and the tilt cylinder simultaneously.

Time consumption: The most common agricultural products to be transported and stacked are bales and boxes of fruits or vegetables to a trailer or a truck. An average rectangular bale has a mass of 20-25 kg, whereas mass of fruit boxes may vary from 5-20 kg for small boxes and a few hundred kg for carrying fruit as a bulk material in a bin. Considering 4-6 bales or 10-12 fruit boxes, the forklift load will be in the range of 100-250 kg for most applications for small farm enterprises.

Table 5: Measured time consumption for various loads at 50 m distance

	Time consumption (s)	
Load (kg)	Average	SD
100	74	5
200	72	1
400	68	6
600	69	12

Time consumption of the system was determined for a cycle of loading the forks on the ground level, transporting the loads over 50 m distance at different ground speeds depending on the amount of load and and unloading on the ground level.

Timing was determined for stacking the pallets only for 200 kg load capacity. The operator did not attempt to maintain a constant forward speed for the tractor for each load, but varied the speed depending on the load being transported. Thus, the transport speed reduced as the load increased during the experiments (Table 5).

The high variation in standart deviation might be attributed to the unfamiliar tractor operator to the forklift operations. The operator experienced neck pain and loss of attention as a result of continuous work during the experiments.

The experiments were done continuously, resulting in exhaustive work for the novice operator. Under usual field or farm operations, less strenuous work is likely, which may not cause the same level of discomfort.

The time consumption for stacking the loads was 65 sec for 200 kg loads over 50 m transporatition distance, which approximately corresponded to a capacity of 10 tons h^{-1} for the tractor-forklift system for transporting the the loads already placed on pallets.

CONCLUSION

The results of this study could be summarized as follows:

- A tractor mounted forklift consisting of a single acting lift cylinder and a double acting tilt cylinder was tested in this study. The forklift has a load capacity of 600 kg, a mass of 290 kg, load center of 525 mm and consists of a single mast to reduce the cost as much as possible
- The maximum fork height and the maximum lift height are 1950 mm and 1500 mm, respectively when the tractor lift arms at lowered position. With the aid of lift arms of the tractor lifting height can be increased up to 2020 mm

- Lifting speed and lowering speeds were 0.065 and 0.13 m sec^{-1}, respectively depending on the load on the forks
- Maximum laod capacity of 600 kg can be safely lifted at load centers greater than the specified load center of 550 mm on flat surfaces and on terraines with small slopes
- On inclined roads up to 11°, static stability is maintained as long as the load center is not greater than 500 mm with the maximum load capacity
- This simple and cost-effective design can be effectively used for materials handling in animal production, such as bales and feed materials in bags and for transporting agricultural materials in containers

ACKNOWLEDGEMENTS

The researchers would like to thank to the Scientific Projects Management Office of Kahramanmaras Sutcuimam University for the support of this study (Project no. 2007/2-2).

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