A Hitch Hook Device for Improved Mobility for Farm Tractor with Unpowered Trailer

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A new hitch hook device for the four-wheel drive farm tractor pulling an unpowered trailer was constructed and tested. The device allows for a heavy load on the hitch hook without risking stability. A hydraulic cylinder creates a force between the trailer frame and the upper three-point attachment that redistributes weight from the load to the tractor's front axle. The device also includes a mechanical construction with joints and a sliding surface that allows the cylinder to be directed straight backwards from the tractor.

A hydraulic regulation system was used to manipulate the force developed by the cylinder. Using this device it was possible to transfer an additional 770 kg from the trailer's unpowered wheels to the powered wheels of the tractor while maintaining weight distribution on the front axle (about 25 % of the tractor's total weight).

The traction force increased roughly in proportion to the increased weight on powered wheels. This corresponded to a 15 % increase in traction force on the relatively heavy tractor used in this study. The same traction increase, about 15 %, was also achieved when using four-wheel drive instead of rear-wheel drive. The hitch hook device also resulted in less skidding and increased uphill mobility of tractor with trailer.

For more generalized usage of the device, the design needs to be simplified and adapted to fit various tractor-trailer combinations.

Key words: mobility, hauling, traction force, rearing, skidding, off-road transport, hitch hook

Introduction

The mobility of an off-road vehicle is significantly affected by the weight distribution between powered and unpowered wheels. The all-wheel drive, as on most forwarders, provides the optimum 100 % weight on powered wheels. A four-wheel drive farm tractor towing a loaded unpowered grapple loader trailer has only about 50 % of the total weight on powered wheels. Heavy load on trailer wheels often results in high ground pressure, which in combination with skidding tractor wheels, causes ground damage such as ruts. Deep ruts will according to Jansson and Johansson (1998) collect water during precipitation and may increase soil erosion and waterlogging.

The optimum choice improving mobility in terrain is to have powered wheels on the trailer. However, this solution is often too expensive for the tractor owner. Out of 70 000 tractor trailers used in forestry in Sweden less than 1 000 have powered wheels. Another way to increase the weight on powered wheels is to redistribute a part of the load from the trailer to the hitch hook. However, using conventional technique, this may most likely cause the tractor to rear when driving uphill or during hard pulling.

Further, when using conventional technology it is necessary to keep a relatively low load on the tractor hitch hook to avoid rearing when driving uphill and when high pulling forces are needed. This means that small loads or aggressive anti skidding devices should be used in difficult terrain. Tests show (Gullberg 1992) that at least 25 % of the total weight should be on the front axle of the tractor when driving in difficult terrain.

The importance of weight distribution, for avoiding soil damage, is pointed out by Ziesak (2003). Wästerlund (1994) also pointed out that avoiding damage to the ground and tree roots is important in order to minimise the environmental impact at selective cuttings or thinning operations.

One of the main advantages considering 4-wheel drive in terrain is that good steering and high pulling capacity can be maintained at the same time if a high proportion of the weight of the tractor will be on the front axle. The risk for rearing will be small and the tractor safe to drive. The more the hitch hook on a conventional tractor vehicle is loaded the less is the use for 4-wheel drive. Powered front wheels are of no use when the front wheels are "hanging" in the air.

A new hitch hook device for the four-wheel drive farm tractor pulling an unpowered trailer was constructed and tested. The device has its' roots from comparative studies between tractors with grapple loader and forwarder (Gullberg 1995). At these studies was shown the importance of weight distribution between powered and unpowered wheels.

The idea for improving characteristics for the tractor vehicles was to put more load than normal on the hitch hook and then "move" some of the load on to the front axle with the help of a hydraulic cylinder. The idea was developed further, and a scetch was presented by Pettersson and Wilhelmsson (1992). Nordfjell (1998) made simulations where the suggested hitch hook was one of the alternatives. The simulation results showed that the suggested hitch hook improved mobility for tractors considerably. The risk for rearing would also be reduced.

A hydraulic cylinder creates a force between the trailer frame and the upper three-point-attachment which redistributes weight from the load to the tractorżs front axle. The device also includes a mechanical construction with joints and a sliding surface which allows the cylinder to be directed straight backwards from the tractor. A hydraulic regulation system was used to manipulate the force developed by the cylinder.

Hypothesis

The device will allow for a heavy load on the hitch hook without jeopardizing stability. The hypothesis also stated that the device will increase safety and mobility while reducing ground damage.

Objectives

The objectives of this study were to construct and test a new hitch hook device (based on Pettersson and Vilhelmsson (1992)) for the four-wheel drive farm tractor with unpowered trailer.

Material and method

Machine

The hitch hook device was attached to a 4-wheel driven tractor (modified for forestry use) and with an unpowered grapple loader trailer with a triple bogie. Both tractor and trailer were relatively heavy (Table 1). The hitch hook device was constructed for a lighter vehicle.

Table 1. Data for the tractor and the trailer

Tractor	Valmet 705/4 (forestry equipped)
Machine power	61 kW
Oil pump	46 dm^3/min
Pressure	17 MPa
Wheels	13.6-24/6 (front)
	18.4-34/8 (rear)
Wheel base	2 315 mm
Mass	1 850 kg (front axle)
	3 300 kg (rear axle)
Trailer	FMV 290 (3 – wheel bogie)
Load capacity	8 tonnes
Mass	2 950 kg (including crane)
Load	3 720 kg

Figure 1. Design of the hitch hook device

Test device

The hitch hook was constructed according to Pettersson and Vilhelmsson (1992) with some small modifications. The hitch hook device is shown in Figure 1.

Hydraulic system

The hydraulic regulation technology for the hydraulic pressure in the cylinder needed further development (from basic suggestion). It was easy to adjust to the right level. However, the hydraulic system was in charge the whole time and caused heat. It wouldn't be possible to use the system for longer periods due to heat. For regulation of the hydraulic pressure was chosen to complete the system with an accumulator charging valve which should keep pressure in the system within a chosen interval. To function the valve needs a flow 10 % of available oil flow.

The hydraulic system consists of the following components:

- Hydraulic cylinder (diameter 50 mm, piston 28 mm, stroke length 250 mm)
- Ackumulator charging valve
- Membrane accumulator (1 dm^3, initial pressure 14.4 MPa).
- Pressure limiting valve.
- Three way valve.

The initial pressure for the accumulator causes that there is relatively little oil (0.04-0.13 dm^3) in the accumulator at the desired pressure levels. This means that the accumulator has high capacity for oil at pressure shocks. On the other hand, it becomes empty relatively quickly when pressure falls. During testing the accumulator charging valve was adjusted to keep pressure between 15.0 and 16.5 MPa, corresponding to a pressure of 29.4 – 32.4 kN in the hydraulic cylinder.

The overflow valve opened at about 17 MPa (33.4 kN). The accumulator charging valve can be equipped with different springs for bigger or narrower intervals. At the first tests the valve was equipped for a narrower interval. However, natural vibration then occurred in the system. The vibrations stopped after exchange for a wider pressure interval for the accumulator charging valve.

Weighing was done using 4 scales (Telub 8023) + central unit, and a Piab dynamometer (3000 kg).

Measurement *of hydraulic oil pressure* was done by connecting a pressure gauge (Dynisco IDA 352-3,5C/4-20mA/0-350 Bar) to a data logger via a Butterworth low pass filter. Measured values were collected in a portable Lap Top. Time intervals were msec (25 measurements per sec).

Traction force was measured by using a pull force gauge (load type KSG5, max 100 kN) connected to a data logger.

Skidding was measured when driving a 125 m long slope in an abandoned gravel pit. The surface was even and the inclination was 13.6 %. Driving ground was sand (28 % gravel, 53 % sand, and 19 % sandy soil or more fine graded). The moisture content (weight of water in relation to weight of dry soil) was 7 %. A total of 5 passes for every 4-wheel drive and 2 passes for every back wheel drive was done by random.

Skidding was estimated from difference between the actual number of revolutions for the back wheels of the tractor and the theoretical number of revolutions (no skidding, unloaded wheel). The actual driving distance per wheel revolution varied considerably (Table 2). This depended first of all on a different loaded back wheel radius, but also on whether front wheel driving was used or not.

Table 2. Driving distance per rear wheel revolution on asphalt

Load on hitch hook	Cylinder force	Four wheel drive	Driving distance per rear wheel rev., mm
normal	yes	yes	4877
normal	yes	no	4843
normal	no	yes	4864
normal	no	no	4828
heavy	yes	yes	4851
heavy	yes	no	4813
heavy	no	yes	4833
heavy	no	no	4792

Results

Mass distribution

The tests were carried out with and without the hitch hook device whereby all the other conditions were equal.

The load on the hitch hook was adjusted whereby 25 % of the total weight of the tractor was on the front axle in both main alternatives (Table 3). This could be achieved by moving the load on the trailer. The load on the hitch hook was 13.73 kN at normal load and 24.03 kN at heavy load.

Table 3. Mass distribution on different wheel axles

Alternative	Front axle, kg	Rear axle, kg	Trailer bogie, kg	Proportion of tractor mass on front axle, %	Proportion of total mass on powered wheels, %
Cyl. force + heavy l.	1820	5500	4500	24.9	61.9
Normal load	1600	4950	5270	24.4	55.4
Cyl. force + norm l.	2100	4200	5520	33.3	53.3
Heavy load	1400	6120	4300	18.6	63.6

The alternatives “heavy hitch hook load/no cylinder force” and “normal hitch hook load/cylinder force” were also tested.

Oil pressure

The ability of the hydraulic system to keep oil pressure on a stable level in the cylinder was tested when driving over an obstacle (200 x 200 mm). Oil pressure at driving speed 0.50 meter/sec and 1.23 metre/sec, respectively is shown in Figure 2. Increased pressure

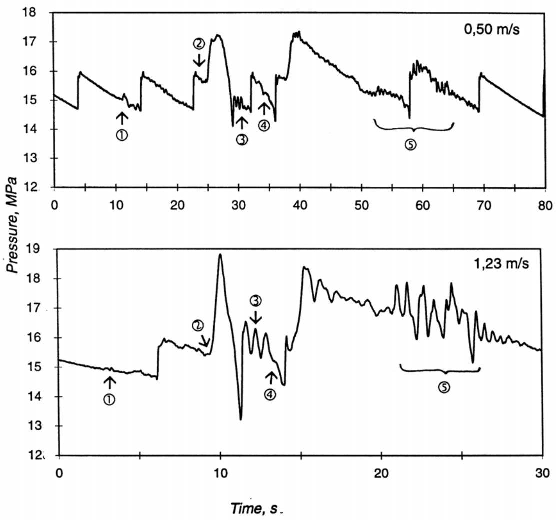

Figure 2. Cylinder oil pressure during passage over a 200 mm high obstacle at different speeds
(1) *tractor starts*
(2) f*ront wheel hits obstacle*
(3) *front wheel ”springs” after passage*
(4) *rear wheel hits obstacle*
(5) *bogie passes obstacle*

occurred first of all when the front wheels entered the obstacle and when the back wheels dismounted the obstacle. Decreased pressure occurred when the front wheels dismounted the obstacle and when the back wheels entered the obstacle. The amplitude for oil pressure variation increased by increased driving speed. Pressure variations (chocks) was considered acceptable considering function and weakening of material.

Oil pressure when driving on forest road and in easy terrain was measured also (Figure 3). At some tests (mainly low oil flow) occurred relatively large fall of pressure, however short in time. It was judged that the accumulator was emptied of oil before new oil could be pumped in. A lower initial pressure in the accumulator was likely to reduce or stop these falls of pressure, but at the same time decrease the possibilities to receive oil at pressure shocks.

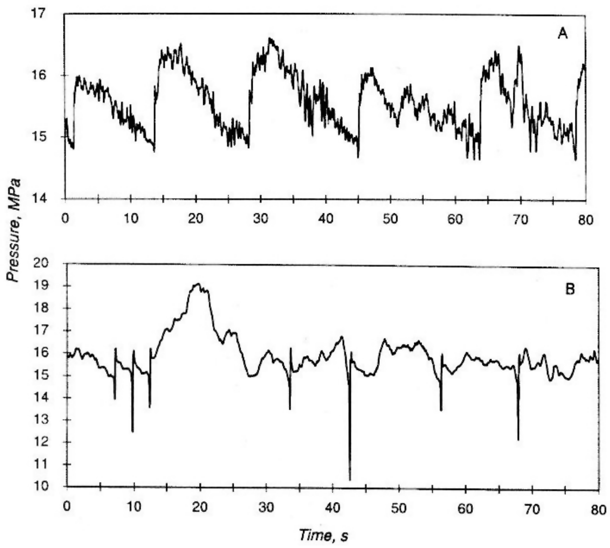

Figure 3. Oil pressure during (A) driving on forest road (5.6 m/s, 2000 rpm) and (B) in easy terrain (1.8 m/s, 1300 rpm)

Traction force

Traction force was measured with the tractor connected to a fixed pole on gravel surface. The measured pulling forces are shown in Table 4. The difference in traction force was 5.2 kN between the main alternatives, representing an increase of about 15 %. The table also shows that cylinder force does not give an increased traction force. Instead the cylinder force reduced traction force as the portion of total weight on the tractor is a little lower at the same hitch hook load. 4-weel drive increased traction force between 5.2 and 8.2 kN compared with back-wheel driving only.

Traction forces at 4-wheel drive was about proportional to the load on driven wheel axles. The friction coefficient (the relation between normal force from driven wheels and traction force) varied between 0.55 and 0.59. Variation can mainly be explained as natural variation and measuring deviations at weighing and measurement of traction force.

Table 4. Maximum traction force before skidding when pulling from a fixed pole on gravel surface

Load on hitch hook	Cylinder force	Four wheel drive	Traction force, kN
heavy	yes	yes	42.6
heavy	yes	no	34.8
heavy	no	yes	44.0
heavy	no	no	38.7
normal	yes	yes	34.0
normal	yes	no	25.8
normal	no	yes	37.2
normal	no	no	32.0

Skidding

Skidding for tractor rear wheels was estimated according to two different definitions. In Table 5 skidding is defined as the difference between actual driving distance and driving distance with loaded wheels on even asphalt. In Table 6 skidding is defined as the difference between actual driving distance and theoretical driving distance with unloaded wheels. Sequence of the repeats showed no significant influence on skidding.

Table 5. Skidding % calculated from actual driving distance for loaded wheels on asphalt as reference. Trials with different letter are significantly (95 %) different

Load on hitch hook	Four wheel drive	Cylinder force	Skidding	Duncan grouping			
Normal	no	yes	19.10	A			
Normal	no	no	14.25		B		
heavy	no	yes	13.54		B		
Normal	yes	yes	11.93			C	
Normal	yes	no	11.23			C	
Heavy	no	no	11.15			C	
Heavy	yes	no	9.75				D
Heavy	yes	yes	9.51				D

Table 6. Skidding % calculated from theoretical driving distance for unloaded wheels as reference. Trials with different letter are significantly (95 %) different

Load on hitch hook	Four wheel drive	Cylinder force	Skidding, %	Duncan grouping				
Normal	no	yes	23.13	A				
Normal	no	no	18.77		B			
Heavy	no	yes	18.36		B			
heavy	no	no	16.47			C		
normal	yes	yes	15.72			C	D	
Normal	yes	no	15.29				D	
Heavy	yes	no	14.42					E
Heavy	yes	yes	13.88					E

Skidding was less when it was estimated with actual driving distance as reference, giving that part of “skidding” in Table 5 is caused by compression of the tyres. Measurements on asphalt also showed that the front wheels are “pulling the rear wheels” causing that the rear wheels are skidding less. This means that the advantage with 4-wheel drive, regarding reduced skidding, is a little overestimated in Table 6. The ranking between experiments was also changed to some extent. However, the difference between the two main alternatives was significant according to both calculation methods.

Driving on slope

A slope (15 – 20 degrees inclination) was tested with different settings. Heavy load on the hitch hook in combination with 4-wheel drive was the only alternative, which could drive the slope. ”The normal alternative” with normal hitch hook load and 4-wheel driving was skidding and got stuck. The alternative with heavy hitch hook load, 4-wheel drive but no cylinder force did not manage the slope due to rearing (Figure 4), i.e. 18.6 % of the total mass of the tractor is not enough on the front axle when driving in difficult terrain. Besides, poor steering capacity occurs before rearing. It is also very unpleasant and dangerous driving close to the limit of rearing.

Discussion

The study shows that the hitch hook device gives advantages considering mobility and safety, and is gentle to the ground. The device increases traction force about as much as 4-wheel drive. The tested tractor and trailer were considerably heavier than the ”normal vehicle” which the hitch hook device was dimensioned for. This means that the relative improvement should be greater on a smaller vehicle.

Figure 4. Rearing tractor during uphill trial with heavy load on the hitch hook, four wheel-drive but no cylinder force. (It was possible to continue up the hill after engaging the cylinder force)

The hitch hook device gives greatest advantages on tractors with relatively low proportion of the weight on the front axle and the crane attached to the trailer. These types of vehicles are the dominant in Sweden. It is possible to load the hitch hook on tractors with a heavy front (e.g. the crane mounted on the tractor with the grapple parked in the tractor-front) even without this device) without risking rearing. The case is the same for a tractor with a front loader. It is also possible to load the front axle on the tractor with front-weights and fluid in the tyres in order to manage a high load on the hitch hook. One disadvantage is that the extra weight makes the vehicle heavier than necessary. This causes extra ground damage and higher fuel consumption. The idea behind the hitch hook device is to use the payload as “front-weight”.

The test of the hitch hook device was regarded as ”worst situation” giving heavier external forces than are normally obtained at normal use. However, speed at forestry use is normally lower, and obstacles will seldom hit both wheels on the axle at the same time.

One limiting factor can be to use a desired load on the hitch hook at a certain load weight. The wood must be placed as close as possible to the tractor at the same time as the bogie on the trailer is placed at the very end. However, this can be done without risking stability and steering capacity. Attaching the crane on the tractor gives advantages considering weight on the front axle on the tractor as well as the possibility to load the wood close to the tractor.

It should be possible to attach this hitch hook device on all types of trailers. The basic principles for mobility and manoeuvrability are, after all, valid for roads and open fields. The price for the device can then be split between e.g. forestry and agriculture. Adjustment of different tractors and trailers for use of the tested device will probably be a big problem. This will probably lead to a need for further standardisation.

In conclusion, the hypothesis and the basic idea behind the device were true. However, the relative effect of the device in the study was not as high as assumed. The fact that both tractor and trailer were heavier than the drawbar construction was designed for might be one explanation. The improvement should, therefore, be greater on a more “normal” vehicle combination. The effect of the device is indicated to be greatest on tractors with low to normal weight distribution on the tractor□s front axle and the crane mounted on the trailer. These types of vehicle combinations dominate in Sweden. One conclusion of the study is that there is no need for the construction of very "front-heavy" tractors (e.g. tractors with front loader or tractor-mounted crane with a front-mounted grapple) though they also allow for a high hitch hook load without jeopardizing stability.

The idea regarding a cylinder mounted directly between upper three-point-attachment and the central pipe of the trailer frame has thereby great advantages. Attachment and connection of trailer will be easier and the weight will be lower. Further development should therefore be to solve the problems regarding articulated joints. Cost for hydraulic components to the tested hitch hook device might also be too high for a more common use. One possibility to get lower cost could be to (instead of controlling technology) use a closed system with cylinder and a considerably bigger accumulator, which gives the cylinder a "springy" function. Such a system must be "loaded" by manual or automatic filling at certain intervals, which will be longer the less leakage and the bigger accumulator.

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КРЕПЛЕНИЕ ДЛЯ СЕЛЬСКОХОЗЯЙСТВЕННОГО ТРАКТОРА С ПРИЦЕПОМ, УЛУЧШАЮЩЕЕ ПРОХОДИМОСТЬ

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Резюме

Создано и испытано новое крепление для четырехколесного сельскохозяйственного трактора с прицепом. Крепление делает возможным повышенную нагрузку на крюк без сопутствующей этому угрозы поднятия передней части. Гидравлический цилиндр, соединяющий балку прицепа и верхнюю трехточечную опору, перераспределяет вес груза прицепа на переднюю ось трактора. Приспособление состоит из механической конструкции с шарниром и повехностями скольжения при помощи которой цилиндр всегда направлен четко назад относительно трактора.

Для распределения мощности гидравлического цилиндра используется гидравлическая система управления. При использовании крепления можно дополнительно перераспределить 770 кг с ведомых колес прицепа на ведущие колеса трактора, сохраняя при этом равномерное распределение веса между передней и задней осями трактора (около 25% от общего веса трактора на переднюю ось).

Растягивающая сила растет приблизительно пропорционально увеличению нагрузки на ведущие колеса. Это соответствует увеличению растягивающей силы на 15% для относительно тяжелого трактора, используемого при тестировани. Такое же увеличение силы, приблизительно на 15%, достигалось и при использовании трактора с четырьмя ведущими колесами вместо двух задних. Крепление также обеспечивает уменьшение скольжения и улучшает проходимость по холмистой местности.

Для более обширного использования приспособления необходимы упрощения конструкции делающие возможным использование крепления в различных сочетаниях трактора с прицепом.

Ключевые слова: проходимость, транспорт для пересеченной местности, растягивающая сила, задирание, скольжение, прицепной крюк.