Performance of an electronic control system for hydraulically driven forestry tandem trailers

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Abstract

Timber transportation can be a complex operation because variations in timber types and soil characteristics can require changes to the vehicles and techniques used. Furthermore, this operation can be dangerous in unfavourable soil conditions (e.g. frozen and muddy ground). A solution to the problem is the use of mechanically or hydraulically driven trailers. The object of this study was to determine whether an innovative electronic control system for trailers equipped with motor axles, could be adapted to the hydraulic transmissions usually mounted on the forestry tandem trailers. The control system consisted of software that is able to modulate the forward speed of the trailer to that of the tractor as a function of the force presented on the hooked components. The control system mounted on forestry tandem trailers was found to have good performance and the versatility of the forestry tandem trailer was improved. Trailers equipped with hydraulic drive and the control system performed similarly to trailers fitted with mechanical drives normally used in forestry. However, unlike the latter, they had a higher ground clearance and were lighter because the absence of motor axle.

It was considered that the control system increased safety levels because the tractor was protected from potentially dangerous oscillations generated by the trailer whilst driving on poor roads.

Keywords

Timber transport, forestry trailer, motor axle, electronic control

1. Introduction

Timber recovery adds to the complexity of forestry operations, but it offers a significant opportunity to increase efficiency, and reduce harvesting and management costs (Windisch et al. 2013).
Forestry in Italy is characterised by steep terrains and high ownership fragmentation (Spinelli *et al*., 2009). These factors have tended to slow down the introduction of mechanised harvesting and help explain the current prevalence of labour-intensive operations (Magagnotti *et al*., 2012). Thus, the introduction of mechanisation should be development of versatile low-investment machinery that could offer a suitable balance between capital and labour inputs (Spinelli *et al*., 2013).

In terms of both energy (Antoniade *et al*., 2012; Lindholm, & Berg, 2005; Angus-Hankin *et al*, 1995) and economics (Hamsley *et al*., 2007) timber transportation is most expansive part of the timber production process. In addition, this operation can be complex because variations in timber types and soil characteristics alter the vehicles and techniques that can be used.

Furthermore, timber harvesting is usually performed in winter and in spring when transport can be difficult and dangerous because of the unfavourable ground conditions (e.g. frozen and muddy). In order to obtain high productivity it is necessary to use specifically designed forestry machines. These machines are often heavy and when there is poor traction, they can create deep rutting and soil compaction (Wästerlund, 1992, Nadezhdina et al. 2006, Sirén et al. 2013). The use of trailers could be a useful alternative because they have a low mass and therefore cause reduced pressure on the soil (Lindroos and Wasterlund, 2014). Nevertheless, the use of trailers, in some cases, can be dangerous because, in presence of a little traction, they can push the tractor off the road because the tractor has a small mass compared to gross mass of the trailer.

A solution to this problem is the use of driven trailers. In this case, the gross mass of the trailer improves the traction of the combined vehicles (i.e. tractor plus trailer). At present, there are two methods to drive the motor axle of a forestry trailer: mechanical and hydraulic drives. With mechanical drive motion is provided by a cardan shaft that connects the synchronised PTO of the tractor to the motor axle of the trailer. With this transmission system, the drive ratio is constant and it is only possible to couple the trailer with the tractor for which it was designed.

Hydraulic transmission does not generally allow for the management of the speed of the tractor to match that of the trailer and, for this reason, such systems are usually only used in forests for transportation over short distances. Unlike mechanical transmission, this solution has the potential advantage of not causing damage to components during hard work, if viscous joint slippage is present. Unfortunately, for the same reason, hydraulic transmission cannot be used downhill where there is the necessity to have maximum tyre grip. Nevertheless, hydraulic systems are frequently mounted on forestry trailers to permit coupling the trailer with different tractors and they can be mounted on trailers with two axles in tandem.

A traction roller powered, by a hydraulic motor has been inserted between the two tyres of bogie (Spinelli, 2000). The roller has ribs which fit between the lugs in the tyre and provide the traction at all positions of the bogie. The traction roller does not slip on the tyre or cause damage and the system has high ground clearance (up to 750 mm) because there are no axles under the frame of the trailer.

Recently, in order to reduce the negative aspects of mechanical transmissions, the University of Turin, has been developing an innovative electronic control system for motorised axles (Manzone, & Balsari, 2015). This system is able to correlate the forward speed of the tractor with that of the trailer independent of the tractor to which it is coupled.

The object of this study is to determine whether the developed electronic control system could be adapted to the hydraulic transmission system that is mounted on the forestry tandem trailers.

2. Materials and methods

The system developed by the University of Turin consisted of specific software that was able to modulate the oil flow to the hydraulic motors

mounted on the motor axle of the trailer using electronic control of hydraulic pump as a function of the force presented to the hooked components. The software is able to correlate the forward speed of the trailer to that of the tractor through information provided by a potentiometer fitted behind to the towing eye of the trailer. Therefore, independent of the tractor used, the trailer following increases or reduces its forward speed as function of the tensile or compressive force present on the drawing eye (Manzone, & Balsari, 2015).
In detail, when the tractor pulls or pushes the trailer causes linear movements of the drawing eye that are recorded from the potentiometer and processed by the electronic control unit. In this way, the electronic control unit modulates the oil flow inlet to the hydraulic motors mounted on the motor axle until the forward speed of the trailer is equal to that of the tractor. When the drawing eye reaches the neutral position (initial position), the forward speed of the trailer is maintained constant. At this point, the trailer follows the tractor without causing tensile or compressive force on the drawing eye.

In order to minimize modifications to the hydraulic equipment usually mounted on forestry trailers, the oil modulation was carried out using an electro valve mounted on the primary pipes. The force present on the towing eye was measured using disc springs made of carbon steel interposed between the tightening nut and the bushing welded to the trailer’s towing arm. The internal diameter of the spring disc was larger than that of the towing pin so that the latter could slide into the disc

springs. The potentiometer screwed behind the towing eye transformed towing eye movements in the electrical signals and transmitted them to the electronic control unit (Fig. 1). The electronic control unit processed the data and powered the electric valves to modulate the force.
The choice of the number, sizes and arrangements (in series or in parallel) of the disc springs can be varied depending on the total mass of the trailers and the sensitivity that is assigned to the system.

During the tests, the control system was mounted on a typical forestry trailer fitted with two axles in tandem (NOKKA® MV 1230HD) (Table 1).

This trailer was manufactured with a hydraulic transmission system able to perform a pulling force of 17 kN with an oil pressure of 19 MPa. In the test, the hydraulic system remained unchanged but was supplemented only with the electrical proportional valve (EPV16B Eaton Corporation PLC, United States).

The electronic control unit and the proportional valve were placed on the tractor in order to have easy access and also to protect from possible damage during use.

Four disc springs in series with 45 mm internal diameter and 100 mm external diameter were mounted on the drawbar eye. Behind the eye a potentiometer (317-780, RS Components, Milan, Italy) with 5 mm stroke was placed. In order to record all the drawbar eye movements (back and forth), the point zero of the potentiometer was set up in its half stroke.

Engaging and disengaging of the system was achieved automatically, setting the lever of the hydraulic distributor of the tractor to which the hydraulic pipe was linked.

When the system was activated, the driver was warned by an indicator.

The functionality of the developed system mounted on the forestry trailers with two axles in tandem was assessed by determining the synchronisation of the trailer forward speed with that of the tractor (Manzone, & Balsari, 2015). The speed synchronisation was determined through data acquisition from the potentiometer mounted behind the towing eye. This is able to translate the towing eye position with respect to “0 point” (neutral point) in different intensity current pulses (the further one moves away from the “0 point”, the greater is the current intensity). Specifically, when the values from the potentiometer were positive, the tractor pulled the trailer, whilst when the values were negative the trailer pushed the tractor. The displacement range of towing eye was of 5 mm (+ 2.5 mm).

The tests were carried out using a 4WD tractor (Newholland® TS100) with a nominal power of 74 kW and a mass of 4.4 t. In the tests, the trailer was tested with a full mass of 2.290 t (trailer unloaded) and 4.5 t (trailer loaded). To provide mass during the tests, the trailer was loaded with concrete blocks.

The tests were carried out using two different itineraries traced on natural soil with the presence of curves (Left and Right) and different slope conditions. Itinerary 1 had a length of about 300 m on a flat area of turf with two curves of 180° and a radius of curvature of 25 m; itinerary 2 had a length of about 120 m and was realised in an area with an average slope of 30% and bare soil. These itineraries were considered representative of electronic control system testing because showing the main characteristics of forestry roads (e.g. curves and a slope of 30%) (Epstein et al, 2006). The tractor and trailer operated with three different forward speeds (2-3-4 km h^{-1}), and for itinerary 2, they were operated in two directions (uphill and downhill) and with constant forward speed (3 km h^{-1}).

During the test the tensile force exerted by the tractor to pull the trailer was measured. This measurement was performed using a digital dynamometer (FH50k, SAUTER, Basel, Switzerland) with a capacity of 50,000 N and a resolution of 10.0 N.

3. Results

In the tests, the control system showed good results because it was able to maintain the forward speed of the trailer similarly to that of the tractor. In all tests the electronic control of the oil hydraulics kept the towing eye of the trailer in "neutral" position (potentiometer's accuracy 0.2 mm).

Operating under normal conditions (i.e. with the control system inactivated) and on flat ground, the towing eye tended to move forward increasing the trailer forward speed. This situation was different when the control system was activated. In this case, the towing eye movements were limited and movements were mainly due to the unevenness present on the road (Fig. 2).

A similar situation occurred during second itinerary where the ground had different slopes. The values obtained highlighted that, independently from the travel direction (uphill and downhill), the control system was able to reduce the thrusts on the coupling pin of the tractor.
When the control system was disengaged the trailer pulled back the tractor going uphill and pushed forward the tractor going downhill, but when the control system was activated the towing eye remained in neutral position (accuracy +/- 0.1 mm) in any operating condition without causing significant disturbance to the tractor (Figs. 3, 4). The maximum displacement range of the towing eye (1.42 mm) was obtained in uphill direction with the control system disengaged (Fig. 4).

Similar dynamics were obtained when operating with a loaded trailer (Figs. 5, 6). In this case, the maximum displacement range of towing eye, again with the control system disengaged was 2.27 mm (about 90% of theoretical towing eye movement) (Fig. 6).

The peaks highlighted in all the performance figures were mainly due to the unevenness on the itineraries.

With the control system disengaged, the tensile force necessary to tow the trailer was proportional to the trailer full mass and to the road slope, but with the system engaged, the maximum tensile forces required were similar (between 2590 and 3750 N) for all the operating conditions (Table 2).

4. Discussion

The tests highlighted that by using the control system it was possible to control the forward speed of the trailer to that of the tractor to which it is coupled. In fact, tests showed that the electronic control system was able to maintain the towing eye in the position "zero" properly modulating the oil flow rate to the hydraulic motors. Good performance was found in all the conditions tested (different slopes and itineraries).

Furthermore, the tests showed that independent from the trailer mass the forces acting on the towing eye were limited. The force required to activate the control system was always less than 4000 N, a value commonly obtained by tractors operating in forestry yards.

Unlike the standard hydraulic drive system, that can be used only for short distances, It is likely that the control system allowed the hydraulic drive to be used long distances without compromising the life of the tyres or mechanical parts involved. In addition, it is also possible to use the hydraulic system going downhill because the control system is able to reduce the forward speed of the trailer to limit the forces on the coupling device.

The control system showed, therefore, a high level of versatility; it is possible to mount all the parts of the control system either on the tractor or the trailer. By mounting the system on the tractor, the trailer can be changed easily making it possible to use different trailers with the same tractor. By mounting all the control system on the trailer, it is possible to limiting the investment of the forestry companies because it is possible to share this investment and to use the same trailer with different types of tractor.

The new developed system, working with the same tensile forces in different operating conditions, should allow the general safety level of tractor use to be increased because tractors are protected from dangerous oscillations that can currently be generated by the trailer while driving on forestry roads.

Furthermore, the device setup should be able to guarantee the same performance with different oil temperatures because the electronic central unit varies the oil flow rate until the towing eye returns to its initial position (neutral point) regardless of oil density.

Finally, in some forestry operations, the trailer is not economically viable compared to a conventional forwarder for its limited load (Eriksson 1998). The use of this control system could permits to increased loads to be used in a wider range of operating conditions.

5. Conclusions

The innovation system mounted on forestry tandem trailers guarantees good performances and the improved versatility of the forestry tandem trailer. On the bases of the results obtained in this work, it is possible to assert that, trailers with hydraulic drive equipped with this innovative system show performances similar to trailers with mechanical drive normally used in forestry, but unlike the latter, they have a higher ground clearance and are lighter because the motor axles are not present. Furthermore, thanks to its control system, this also increases the general safety level because the tractor is protected from the dangerous solicitations generated by the trailer while driving on bad roads. For these reasons, the innovative system tested can be considered a viable alternative to the trailer traction systems currently available on the market.

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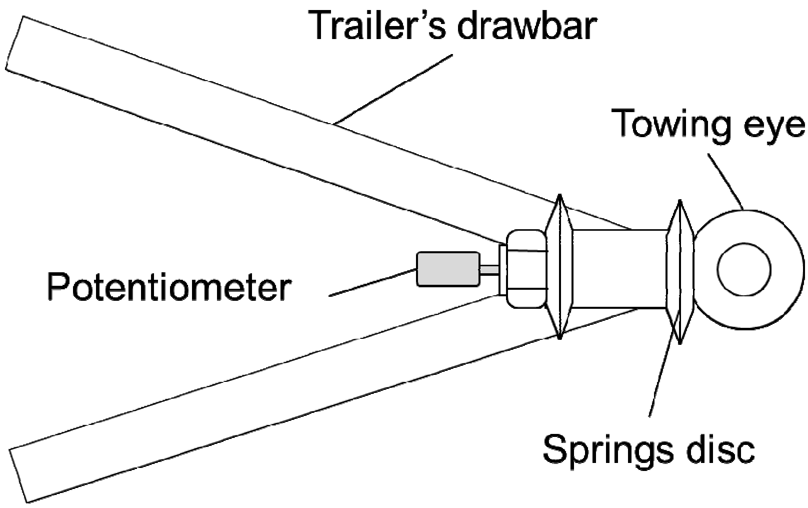

Fig. 1. System scheme to determine the force on the towing eye.

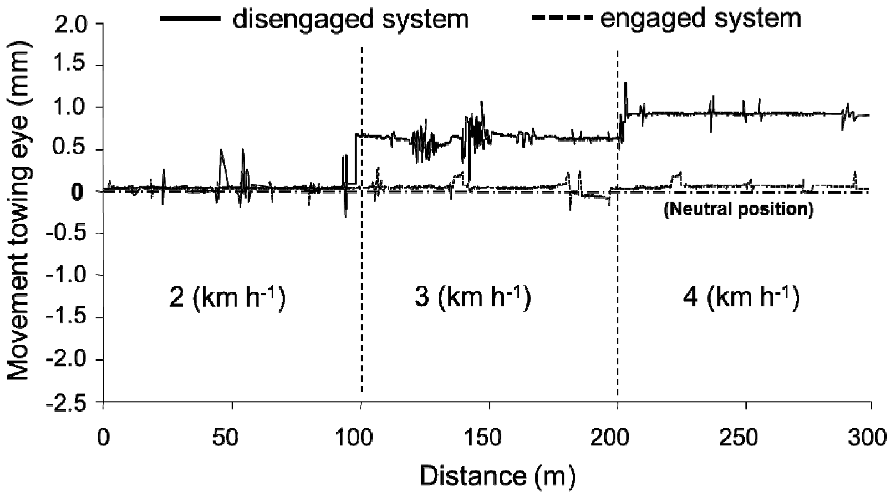

Fig. 2. Towing eye position with disengaged/engaged control system with different forward speeds.

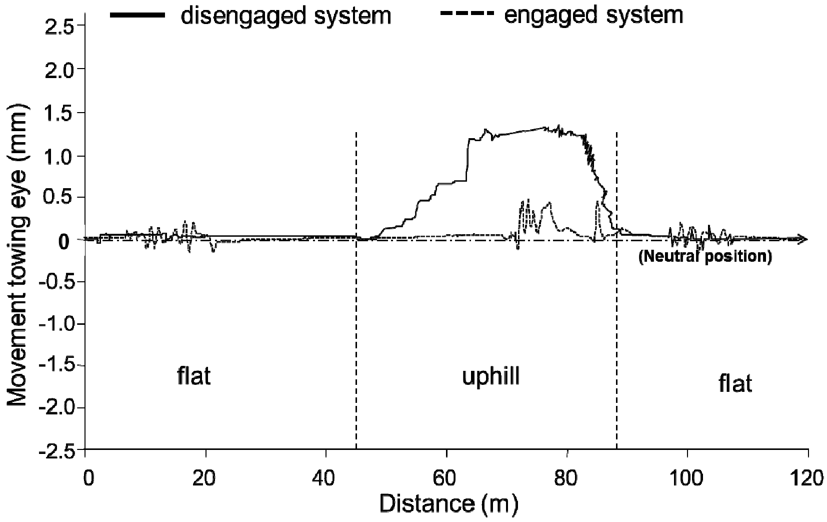

Fig. 3. Towing eye position with disengaged/engaged control system in an uphill situation (trailer unloaded).

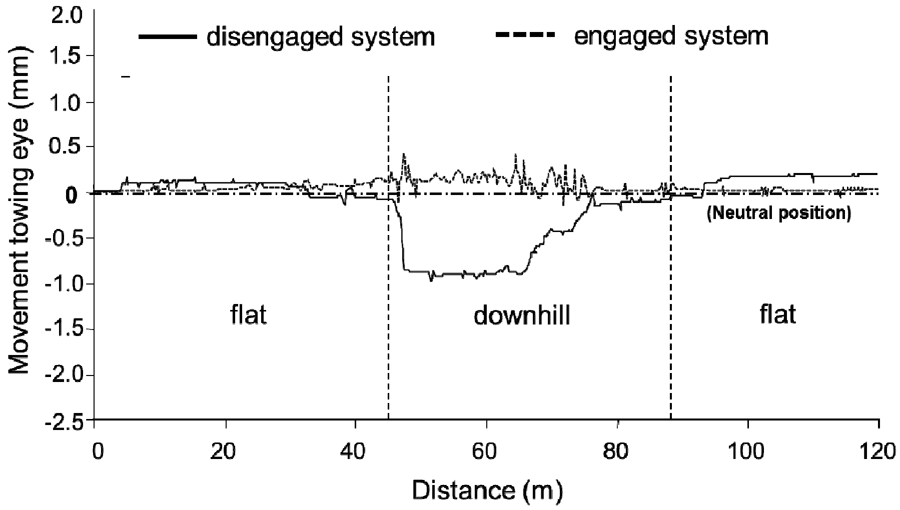

Fig. 4. Towing eye position with disengaged/engaged control system in a downhill situation (trailer unloaded).

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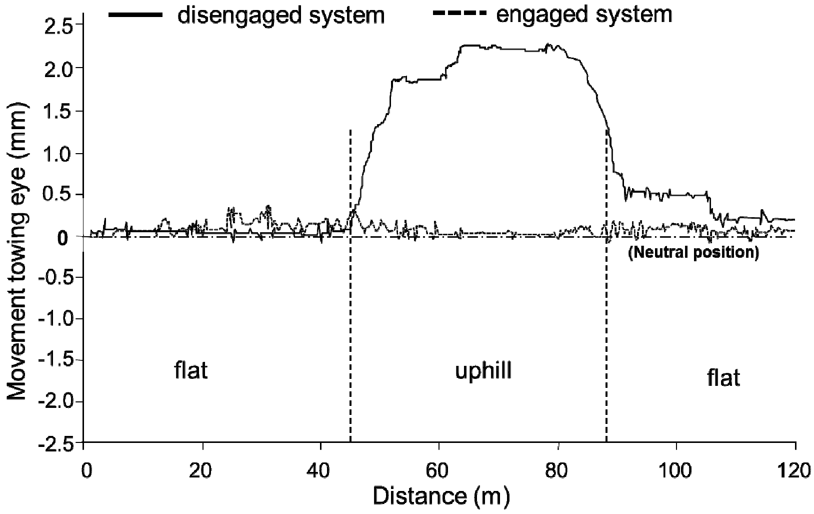

365 **Fig. 5.** Towing eye position with disengaged/engaged control system in an

366 uphill situation (trailer loaded).

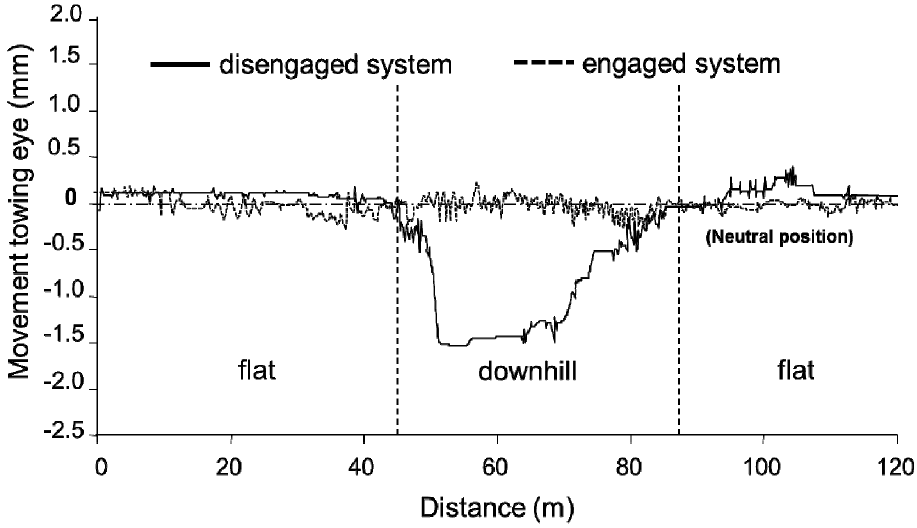

Fig. 6. Towing eye position with disengaged/engaged control system in adownhill situation (trailer loaded).

Table 1

Technical characteristics of the trailer used in the trails.

Nokka MV 1270HD		
Width	(m)	2.38
Length	(m)	6.10
Height	(m)	2.71
Loading area	(m^2)	3.00
Ground clearance	(m)	0.71
Tyres	550/45-22.5 ELS	
Loading capacity	(t)	12

Table 2

Maximum tensile force with control system engaged/disengaged

	Slope (%)	Trailer mass (kg)	Exerted force (N)
System disengaged	0	2300	1920
		4500	4200
	30	2300	9200
		4500	21000
System engaged	0	2300	2590
		4500	3200
	30	2300	2790
		4500	3750