Electronic Control of Motor Axles of Forestry Trailers

Marco Manzone, Paolo Balsari

Abstract

Timber transport in the forest is a very complex operation, and expensive from an energy point of view. Furthermore, in some cases, this operation can be very difficult and dangerous in unfavorable conditions of the road surface, which mainly occur in winter (frozen ground) and in spring (muddy ground). The goal of this study was to develop an innovative transmission hydraulic control system for trailer motor axle that would allow correlating the forward speed of the trailer with that of the tractor, which is not necessarily always the same. In detail, the innovative motor axle of the trailer is driven by a hydraulic motor through a pump controlled electronically. A specific software is able to correlate the forward speed of the trailer with the speed of the tractor in any operating situation, thanks to the information given by a potentiometer screwed behind to the trailer component coupled to the tractor. The innovative system developed to control the trailer motor axle provides the possibility to use the trailer with any type of tractor, not requiring long and complex adjustment of tractor and trailer, since it is completely independent from the type of the tractor used.

Keywords: Timber transport, forestry trailer, motor axle, electronic control

1. Introduction

Italian forestry is characterized by steep terrain and high ownership fragmentation (Mason et al. 1999). All these factors tend to slow down the introduction of mechanized harvesting, determining the current prevalence of requirements of labor-intensive operations (Magagnotti et al. 2012). In order to try to solve this problem, versatile low-investment machinery should be developed that could offer a suitable balance between capital and labor inputs (Spinelli et al. 2013).

Among all forestry operations, timber transport is a very complex operation, and also expensive from an energy point of view (Antoniade et al. 2012, Johansson et al. 2006, Lindholm and Berg 2005, Angus-Hankin 1995). Furthermore, in some cases, this operation could be very difficult and dangerous in unfavorable conditions of the road surface, which mainly occur in winter (frozen ground) and in spring (muddy ground).

For these reasons, the use of trailers with motor axle is increasing in large and small forests. The motor axle drive system can be mechanical or hydraulic. In the first case, due to the constant transmission ratio, it is possible to use only the tractor with the tire configuration for which the trailer was designed. Furthermore, to allow this type of transmission, trailer manufacturer companies are forced to use a transmission ratio that can reduce the trailer forward speed by 3–5% compared to the coupled tractor. It is also necessary to allow the convoy to make the curves without having the trailer, which has a smaller radius of curvature, pushing the tractor.

At present, the hydraulic transmission mounted on forestry trailers, generally, does not allow to manage the speed of the hydraulic motor and the system is used in forest only for short distances and only when it is necessary to increase the tires grip. Unlike the mechanical traction, this solution has the advantage to not determine potential breaks of the mechanical components of the transmission, as before breakage of mechanical parts a viscous joint slippage is present but, for the same reason, it cannot be used downhill where it is absolutely necessary to reach the maximum tires grip.

The goal of this study was to develop an innovative transmission hydraulic control system for trailer motor axle that would allow correlating the forward speed of the trailer with that of the tractor, which is not necessarily always the same.

2. Materials and methods

In developing this innovation, efforts have been made to enhance the positive aspects and to reduce those negatives of the two trailer motor axle driving systems (mechanical and hydraulic). To be specific, in the innovative system developed, the motor axle of the trailer is driven by a hydraulic motor through an electronically controlled pump. A specific software is able to correlate the forward speed of the trailer with the speed of the tractor in any operating situation, thanks to the information given by a potentiometer screwed behind to the trailer component coupling to the tractor.

In order to identify more useful components, a market survey was carried out to examine the technical characteristics of the solutions already developed by other Research Centers and manufacturers of agricultural equipment and components.

This investigation showed that all the technical solutions developed could only solve a part of the problem, and required sophisticated components not suitable for forestry conditions. Otherwise, components and solutions used for the innovative system were studied or at least protected by steel guards.

The trailer used for the application of the innovative system is a commercial forestry trailer (Offine Terpa® TM60) with a single motor axle, full load mass of 6.0 t and length and width of 4.0 m and 1.8 m, respectively.

The trailer axle had a transmission ratio of 1/30. A pump (Sauer-Danfoss® M46-20777) was fixed on the rudder with variable torque (37–106 Nm) and under the frame a hydrostatic motor (Sauer-Danfoss® M44-43028) with a displacement of 250 cm^3 rev^{-1}.

A mechanical gearbox was inserted between the hydraulic motor and the axle that could disengage the system when necessary.

The transmission between the gearbox and the axle was realized with a drive shaft. An oil tank (80 liters of capacity) was mounted behind the axle and under the trailer load floor. The electronics central unit was placed at the side of the rudder in order to make an easy access and to protect it from possible damage during the use.

With the aim to modulate the »movement« of the towing eye of the trailer and cushion the impact between the wheels and a possible obstacle present on the soil, the towing eye has been prepared by interposing between the tightening nut and the bushing welded to the rudder of the disc springs made in Carbon steel (Fig. 1).

The size and thickness of the disc springs can be varied depending on the total weight of the trailer and the sensitivity assigned to the system. This latter can also be adjusted using a different number and arrangement of the disc springs (in series or in parallel). Furthermore, the internal diameter of the spring disc must

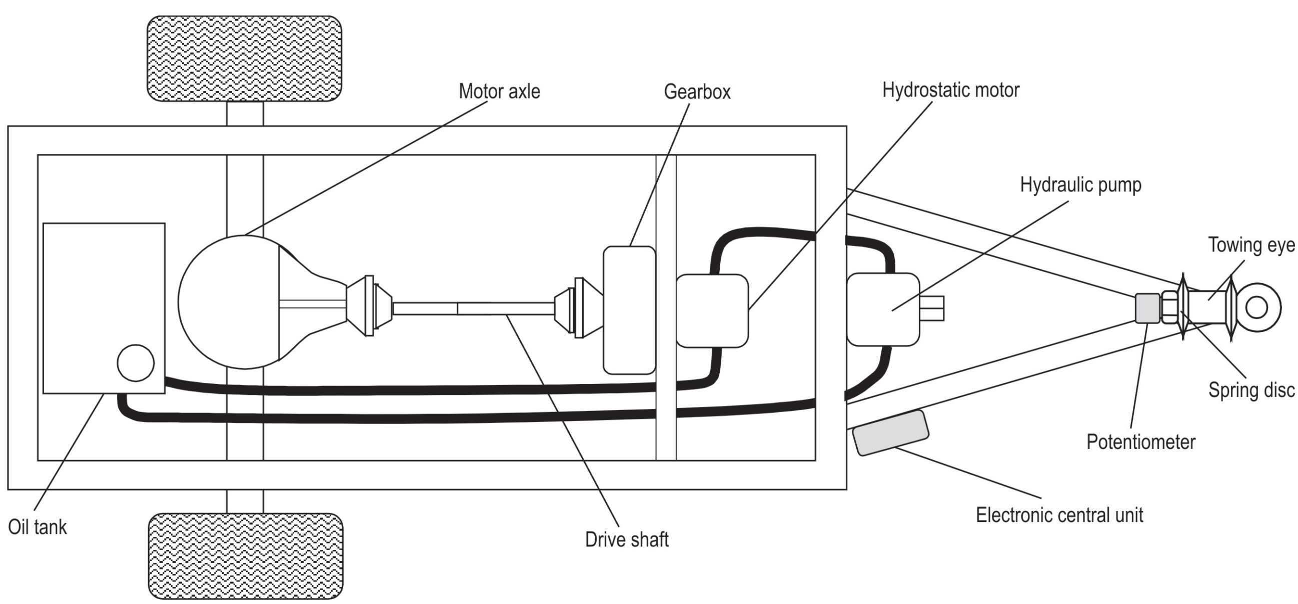

Fig. 1 Scheme of components of the innovative system

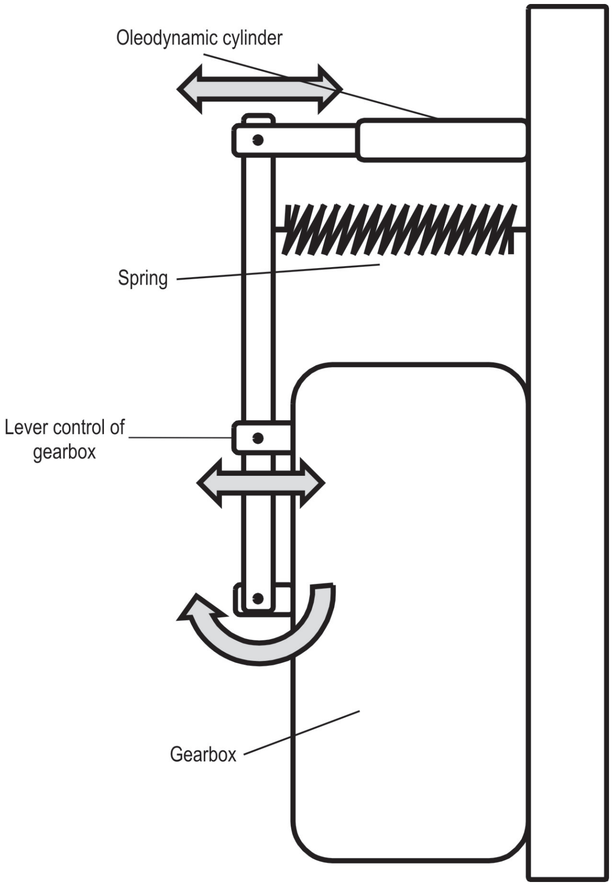

Fig. 2 Scheme of engage/disengage system of the gearbox

be larger than that of the tow pin so that the latter can slide into the disc springs.

The engaging and disengaging of the system is obtained automatically by setting the P.T.O. rotation of the tractor. In fact, activating the P.T.O. of the tractor, a hydraulic cylinder, powered by the hydraulic pump of the trailer, activates the mechanical clutch of the gearbox. The disengaging of the system takes place by a coil spring that, when the P.T.O. rotation is stopped, takes the mechanical clutch of the gearbox back in the initial position.

When the system is activated, a warning green light is switched on (Fig. 2).

In order to assess the functionality of the developed system, field tests aimed at determining the synchronization of the trailer forward speed with the speed of the tractor have been made. The speed synchronization was determined through the data acquired by a potentiometer mounted behind the towing eye. The towing eye is used in order to provide the information to the electronic control unit necessary to modulate the flow and pressure of oil input to the hydrostatic motor, switch the position of the towing eye with respect to »0 point« (neutral point) with current pulses of different intensity (the further one moves away from the »0 point«, the greater is the current intensity). In detail, when the values coming from the potentiometer are positive, it means that the tractor pulls the trailer, while when the value are negative the trailer pushes the tractor.

The trials were carried out using a 4WD tractor (Fiatagri® 88–94) with the nominal power of 67 kW and mass of 3500 kg and a trailer with empty mass of 1180 kg and full mass of 3 tones.

The load of the trailer was made of concrete blocks.

The tests were carried out on different itineraries traced on natural soil (ground) with the presence of curves (L and R) and in different slope condition. Two routes were chosen for the tests: Itinerary 1 had the length of about 300 m in a flat area with turf with two curves of 180° and a radius of curvature of 25 m; itinerary 2 had the length of about 120 meters in an area with an average slope of 30% and in bare soil. The convoys (tractor + trailer) have been operating with three different forward speeds (2–3–4 km h^{-1}), while in itinerary 2, two directions were used (uphill and downhill) with constant forward speed (3 km h^{-1}).

The tensile force exerted by the tractor to pull the trailer has also been measured in each itinerary. This measurement was performed using a digital dynamometer (SAUTER® FH50k) with the capacity of 50 kN and resolution of 10.0 N.

3. Results

In all tests carried out, the electronic system has guaranteed an efficient control of the mechanical coupling, synchronizing the speed of the trailer with the speed of the tractor. This has been proved by the capacity to maintain the towing eye of the trailer in »neutral« position.

Operating on flat soil and with the developed control system not activated, the towing eye tended to move forward increasing the trailer forward speed, while with the innovative system activated, this phenomenon was very limited and the towing eye position also remained stable when operating with different tractor forward speeds. The peaks highlighted in Fig. 3 are mainly due to the unevenness present in the itinerary.

The values obtained in the second itinerary show that thanks to the use of the innovative system, it is possible to reduce to minimum the thrust on the coupling pin of the tractor at different slopes. Fig. 4 and 5

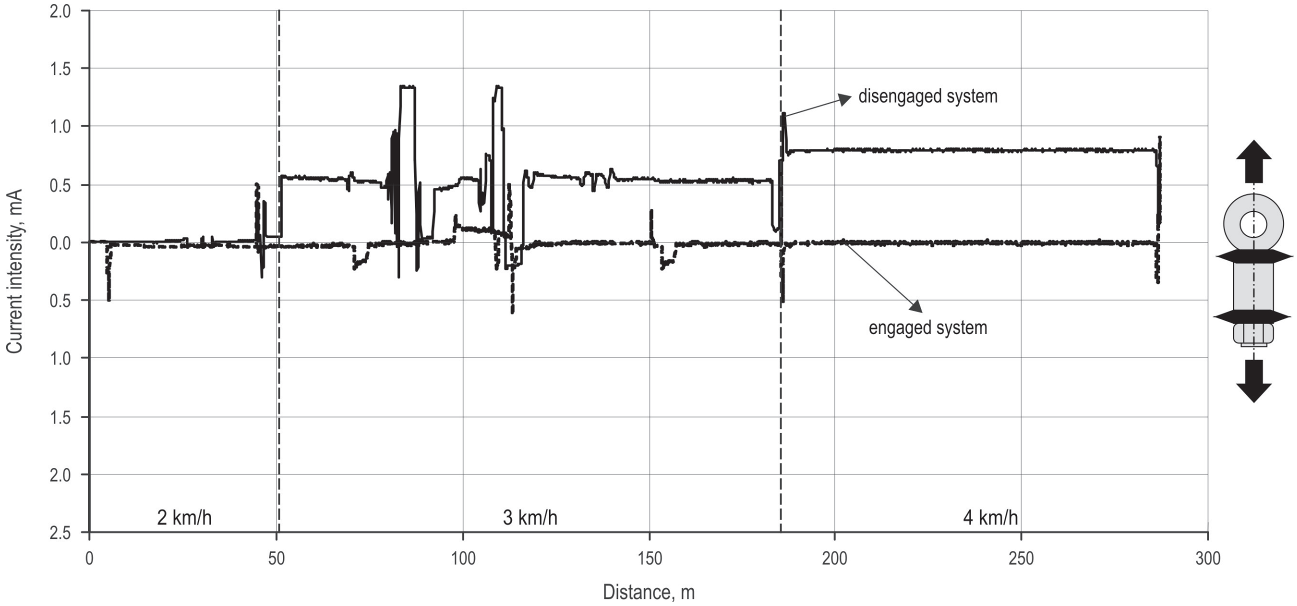

Fig. 3 Towing eye position with disengaged/engaged innovative system with different forward speeds

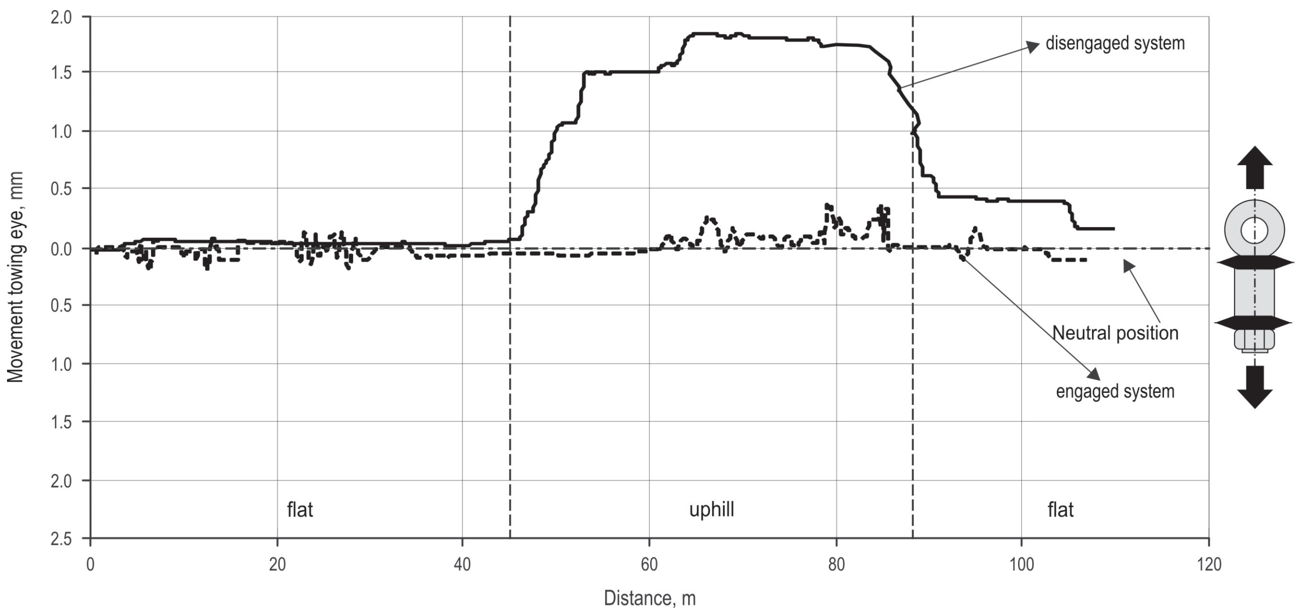

Fig. 4 Towing eye position with disengaged/engaged innovative system in uphill travel

show a neutral position of the towing eye independently from the travel direction (uphill and downhill).

When the developed system was not active, the tensile force required to tow the trailer was proportional to the mass of the trailer and to the slope, and when the system was active, the tensile forces registered in the trails were similar (between 144 and 186 daN) for all the operating conditions (Table 1).

4. Discussion

Graphs showed that the electronic control unit can properly modulate the flow of oil to the hydraulic motor while maintaining the »zero« position of the towing eye, independently from the slope soil.

Furthermore, the innovative system also shows a good performance In circuitous itineraries; in fact, the

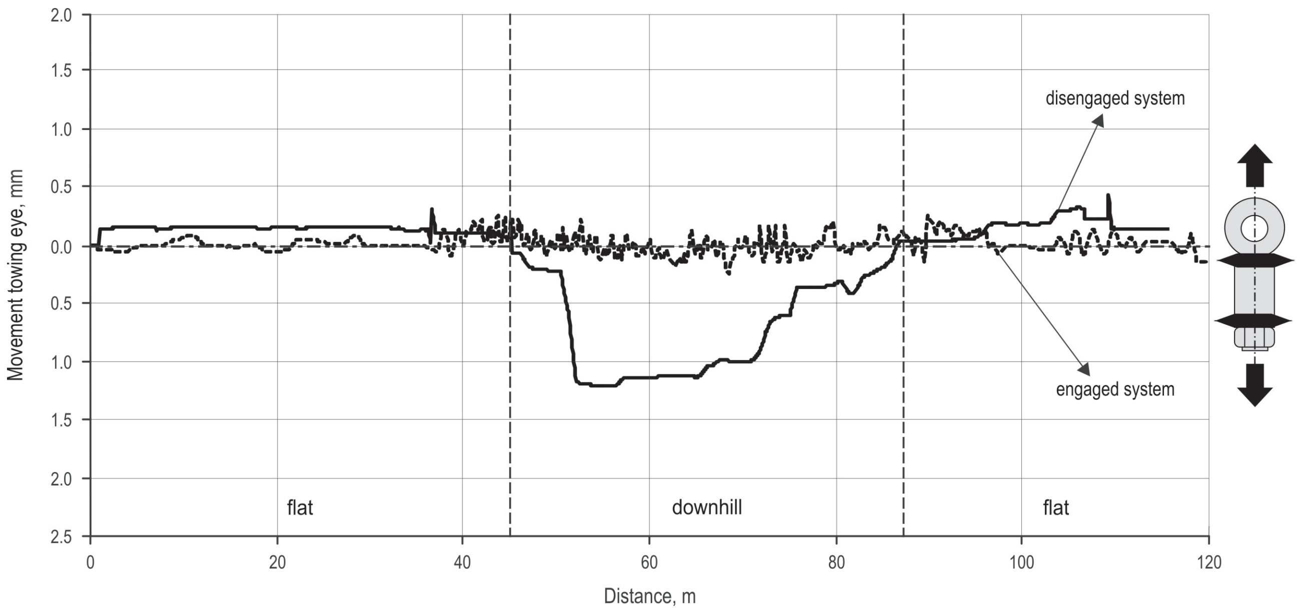

Fig. 5 Towing eye position with disengaged/engaged innovative system in downhill travel

Table 1 Tensile force with deactivated/activated innovative system

	Slope	Trailer mass	Exerted force
	%	kg	daN
Not activated system	0	1180	98
		3000	256
	30	1180	426
		3000	1289
Activated system	0	1180	144
		3000	156
	30	1180	152
		3000	186

trailer, while making a radius of curvature different from that of the tractor, does not generate dangerous pressures like those in tractions where the transmission ratio is the same (mechanical transmission).

Tests carried out have shown that, independently of whether the trailer is loaded or unloaded, the forces acting on the coupling device (trailer–tractor) are limited. The force required to activate the developed system is about 150 daN, and this value that can be ensured by any forestry tractor, including tractors of lower power (Table 1).

The innovative system developed to control the trailer motor axle provides the possibility to use the trailer with any type of tractor, not requiring long and complex adjustment of tractor and trailer, since it is completely independent from the type of the tractor used. Consequently, all the forestry tractors could be used, which reduced the maintenance costs thanks to more uniform yearly hours of use of the tractors. The developed device could also be conveniently used in small forestry companies that cannot purchase a forestry trailer with motor axle due to limited capital. They could share this investment with other forestry companies having the possibility to use the same trailer with different types of tractors.

The new developed system, working with the same tensile forces in different operating conditions, also results in increasing the general safety level, because it protects the tractor from dangerous solicitations generated by the trailer while driving on forestry roads, which happens regularly when the current commercial solutions are used.

5. Conclusions

This innovation system could be considered a viable alternative to the trailer traction systems present today on the market, because it can reduce the farm investment and improve the versatility of the forestry trailer. Furthermore, thanks to its control system, it also increases the general safety level by protecting the tractor from dangerous solicitations generated by the trailer while driving on bad roads.

This developed system is, at present, protected by an industrial patent (n° TO2012A000958) deposited by the University of Turin.

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Authors' addresses:

Marco Manzone PhD.*
e-mail: marco.manzone@unito.it
Prof. Paolo Balsari, PhD.
e-mail: paolo.balsari@unito.it
Università degli studi di Torino – DISAFA
Via Leonardo da Vinci, 44 Grugliasco (TO)
ITALY

* Corresponding author

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