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

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(Article begins on next page)

- 1 **Performance of an electronic control system for**
- 2 **hydraulically driven forestry tandem trailers**

3 **Abstract**

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

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

24

25 **Keywords**

26 Timber transport, forestry trailer, motor axle, electronic control

27 **1. Introduction**

28

29 Timber recovery adds to the complexity of forestry operations, but it offers  
30 a significant opportunity to increase efficiency, and reduce harvesting and  
31 management costs (Windisch et al. 2013).

32 Forestry in Italy is characterised by steep terrains and high ownership  
33 fragmentation (Spinelli *et al.*, 2009). These factors have tended to slow  
34 down the introduction of mechanised harvesting and help explain the  
35 current prevalence of labour-intensive operations (Magagnotti *et al.*,  
36 2012). Thus, the introduction of mechanisation should be development of  
37 versatile low-investment machinery that could offer a suitable balance  
38 between capital and labour inputs (Spinelli *et al.*, 2013).

39

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

45

46 Furthermore, timber harvesting is usually performed in winter and in spring  
47 when transport can be difficult and dangerous because of the  
48 unfavourable ground conditions (e.g. frozen and muddy). In order to obtain  
49 high productivity it is necessary to use specifically designed forestry  
50 machines. These machines are often heavy and when there is poor  
51 traction, they can create deep rutting and soil compaction (Wästerlund,

52 1992, Nadezhdina et al. 2006, Sirén et al. 2013). The use of trailers could  
53 be a useful alternative because they have a low mass and therefore cause  
54 reduced pressure on the soil (Lindroos and Wasterlund, 2014).

55 Nevertheless, the use of trailers, in some cases, can be dangerous  
56 because, in presence of a little traction, they can push the tractor off the  
57 road because the tractor has a small mass compared to gross mass of the  
58 trailer.

59

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

68

69 Hydraulic transmission does not generally allow for the management of  
70 the speed of the tractor to match that of the trailer and, for this reason,  
71 such systems are usually only used in forests for transportation over short  
72 distances. Unlike mechanical transmission, this solution has the potential  
73 advantage of not causing damage to components during hard work, if  
74 viscous joint slippage is present. Unfortunately, for the same reason,  
75 hydraulic transmission cannot be used downhill where there is the  
76 necessity to have maximum tyre grip. Nevertheless, hydraulic systems are

77 frequently mounted on forestry trailers to permit coupling the trailer with  
78 different tractors and they can be mounted on trailers with two axles in  
79 tandem.

80

81 A traction roller powered, by a hydraulic motor has been inserted between  
82 the two tyres of bogie (Spinelli, 2000). The roller has ribs which fit between  
83 the lugs in the tyre and provide the traction at all positions of the bogie.

84 The traction roller does not slip on the tyre or cause damage and the  
85 system has high ground clearance (up to 750 mm) because there are no  
86 axles under the frame of the trailer.

87

88 Recently, in order to reduce the negative aspects of mechanical  
89 transmissions, the University of Turin, has been developing an innovative  
90 electronic control system for motorised axles (Manzone, & Balsari, 2015).

91 This system is able to correlate the forward speed of the tractor with that of  
92 the trailer independent of the tractor to which it is coupled.

93

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

97

## 98 **2. Materials and methods**

99

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

102 mounted on the motor axle of the trailer using electronic control of  
103 hydraulic pump as a function of the force presented to the hooked  
104 components. The software is able to correlate the forward speed of the  
105 trailer to that of the tractor through information provided by a potentiometer  
106 fitted behind to the towing eye of the trailer. Therefore, independent of the  
107 tractor used, the trailer following increases or reduces its forward speed as  
108 function of the tensile or compressive force present on the drawing eye  
109 (Manzone, & Balsari, 2015).

110 In detail, when the tractor pulls or pushes the trailer causes linear  
111 movements of the drawing eye that are recorded from the potentiometer  
112 and processed by the electronic control unit. In this way, the electronic  
113 control unit modulates the oil flow inlet to the hydraulic motors mounted on  
114 the motor axle until the forward speed of the trailer is equal to that of the  
115 tractor. When the drawing eye reaches the neutral position (initial  
116 position), the forward speed of the trailer is maintained constant. At this  
117 point, the trailer follows the tractor without causing tensile or compressive  
118 force on the drawing eye.

119  
120 In order to minimize modifications to the hydraulic equipment usually  
121 mounted on forestry trailers, the oil modulation was carried out using an  
122 electro valve mounted on the primary pipes. The force present on the  
123 towing eye was measured using disc springs made of carbon steel  
124 interposed between the tightening nut and the bushing welded to the  
125 trailer's towing arm. The internal diameter of the spring disc was larger  
126 than that of the towing pin so that the latter could slide into the disc

127 springs. The potentiometer screwed behind the towing eye transformed  
128 towing eye movements in the electrical signals and transmitted them to the  
129 electronic control unit (Fig. 1). The electronic control unit processed the  
130 data and powered the electric valves to modulate the force.

131 The choice of the number, sizes and arrangements (in series or in parallel)  
132 of the disc springs can be varied depending on the total mass of the  
133 trailers and the sensitivity that is assigned to the system.

134

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

137

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

143

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

147

148 Four disc springs in series with 45 mm internal diameter and 100 mm  
149 external diameter were mounted on the drawbar eye. Behind the eye a  
150 potentiometer (317-780, RS Components, Milan, Italy) with 5 mm stroke



151 was placed. In order to record all the drawbar eye movements (back and  
152 forth), the point zero of the potentiometer was set up in its half stroke.

153

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

157

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

159

160 The functionality of the developed system mounted on the forestry trailers  
161 with two axles in tandem was assessed by determining the  
162 synchronisation of the trailer forward speed with that of the tractor  
163 (Manzone, & Balsari, 2015). The speed synchronisation was determined  
164 through data acquisition from the potentiometer mounted behind the  
165 towing eye. This is able to translate the towing eye position with respect to  
166 "0 point" (neutral point) in different intensity current pulses (the further one  
167 moves away from the "0 point", the greater is the current intensity).

168 Specifically, when the values from the potentiometer were positive, the  
169 tractor pulled the trailer, whilst when the values were negative the trailer  
170 pushed the tractor. The displacement range of towing eye was of 5 mm (+  
171 2.5 mm).

172

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

176 loaded). To provide mass during the tests, the trailer was loaded with  
177 concrete blocks.

178

179 The tests were carried out using two different itineraries traced on natural  
180 soil with the presence of curves (Left and Right) and different slope  
181 conditions. Itinerary 1 had a length of about 300 m on a flat area of turf  
182 with two curves of 180° and a radius of curvature of 25 m; itinerary 2 had a  
183 length of about 120 m and was realised in an area with an average slope  
184 of 30% and bare soil. These itineraries were considered representative of  
185 electronic control system testing because showing the main characteristics  
186 of forestry roads (e.g. curves and a slope of 30%) (Epstein et al, 2006).

187 The tractor and trailer operated with three different forward speeds (2-3-  
188 4 km h<sup>-1</sup>), and for itinerary 2, they were operated in two directions (uphill  
189 and downhill) and with constant forward speed (3 km h<sup>-1</sup>).

190

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

195

### 196 **3. Results**

197

198 In the tests, the control system showed good results because it was able  
199 to maintain the forward speed of the trailer similarly to that of the tractor. In

200 all tests the electronic control of the oil hydraulics kept the towing eye of  
201 the trailer in "neutral" position (potentiometer's accuracy 0.2 mm).

202

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

209

210 A similar situation occurred during second itinerary where the ground had  
211 different slopes. The values obtained highlighted that, independently from  
212 the travel direction (uphill and downhill), the control system was able to  
213 reduce the thrusts on the coupling pin of the tractor.

214 When the control system was disengaged the trailer pulled back the  
215 tractor going uphill and pushed forward the tractor going downhill, but  
216 when the control system was activated the towing eye remained in neutral  
217 position (accuracy +/- 0.1 mm) in any operating condition without causing  
218 significant disturbance to the tractor (Figs. 3, 4). The maximum  
219 displacement range of the towing eye (1.42 mm) was obtained in uphill  
220 direction with the control system disengaged (Fig. 4).

221

222 Similar dynamics were obtained when operating with a loaded trailer (Figs.  
223 5, 6). In this case, the maximum displacement range of towing eye, again

224 with the control system disengaged was 2.27 mm (about 90% of  
225 theoretical towing eye movement) (Fig. 6).

226

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

229

230 With the control system disengaged, the tensile force necessary to tow the  
231 trailer was proportional to the trailer full mass and to the road slope, but  
232 with the system engaged, the maximum tensile forces required were  
233 similar (between 2590 and 3750 N) for all the operating conditions (Table  
234 2).

235

#### 236 **4. Discussion**

237

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

244

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

249

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

257

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

266

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

272

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

277

278 Finally, in some forestry operations, the trailer is not economically viable  
279 compared to a conventional forwarder for its limited load (Eriksson 1998).

280 The use of this control system could permits to increased loads to be used  
281 in a wider range of operating conditions.

282

## 283 **5. Conclusions**

284

285 The innovation system mounted on forestry tandem trailers guarantees  
286 good performances and the improved versatility of the forestry tandem  
287 trailer. On the bases of the results obtained in this work, it is possible to  
288 assert that, trailers with hydraulic drive equipped with this innovative  
289 system show performances similar to trailers with mechanical drive  
290 normally used in forestry, but unlike the latter, they have a higher ground  
291 clearance and are lighter because the motor axles are not present.

292 Furthermore, thanks to its control system, this also increases the general  
293 safety level because the tractor is protected from the dangerous  
294 solicitations generated by the trailer while driving on bad roads. For these  
295 reasons, the innovative system tested can be considered a viable  
296 alternative to the trailer traction systems currently available on the market.

297

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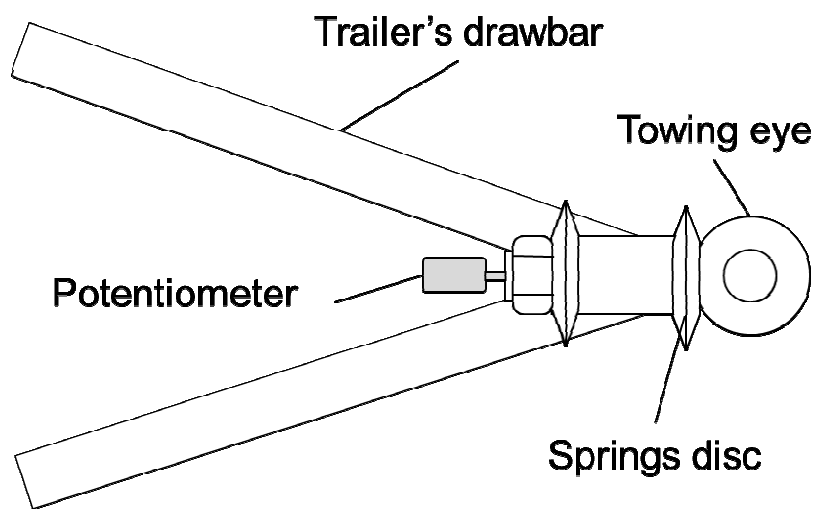
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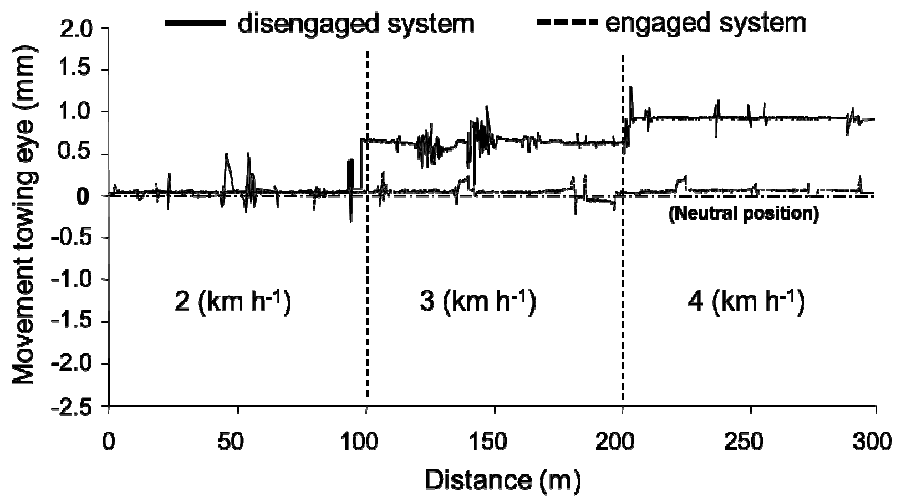
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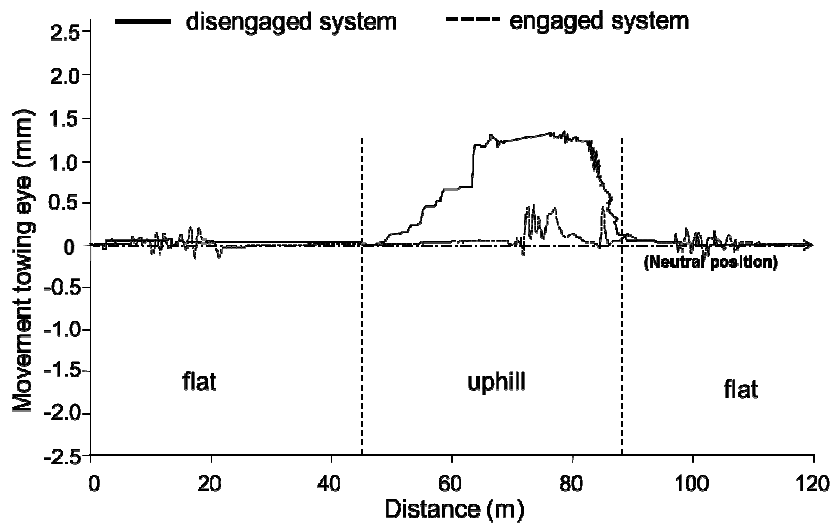
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354 **Fig. 1.** System scheme to determine the force on the towing eye.



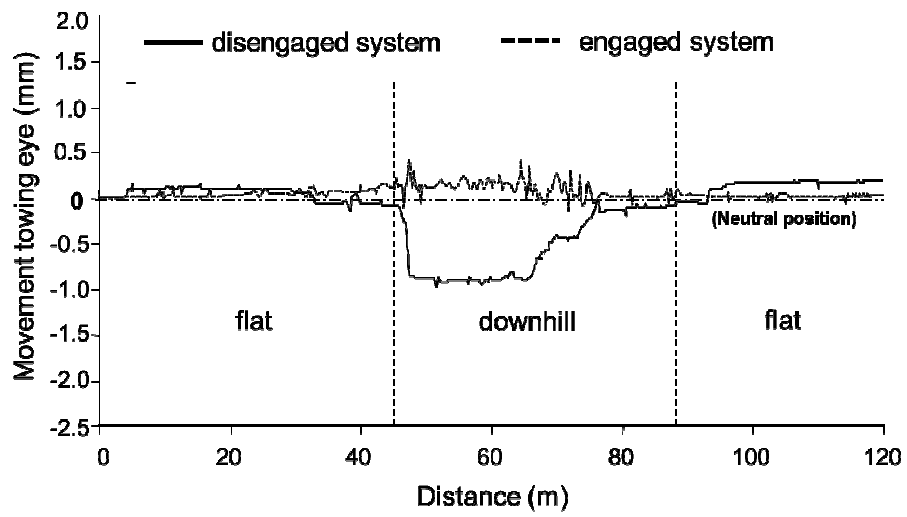
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356 **Fig. 2.** Towing eye position with disengaged/engaged control system with  
 357 different forward speeds.



358

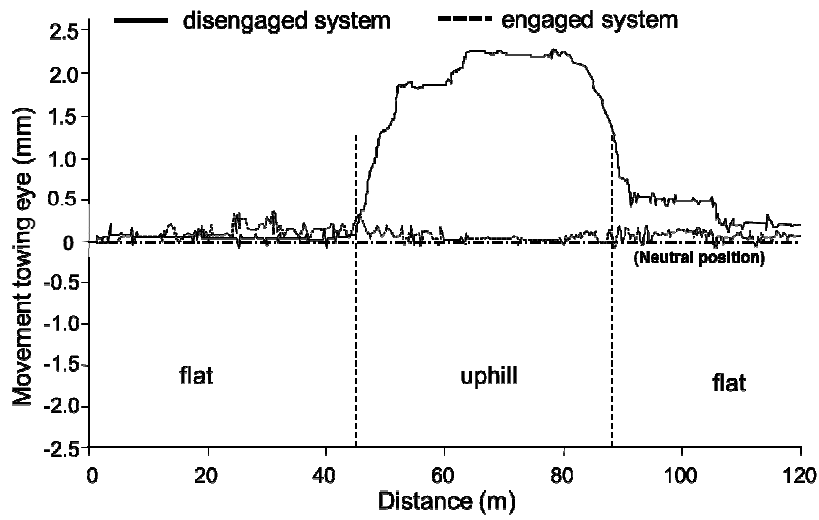
359 **Fig. 3.** Towing eye position with disengaged/engaged control system in an  
 360 uphill situation (trailer unloaded).



361

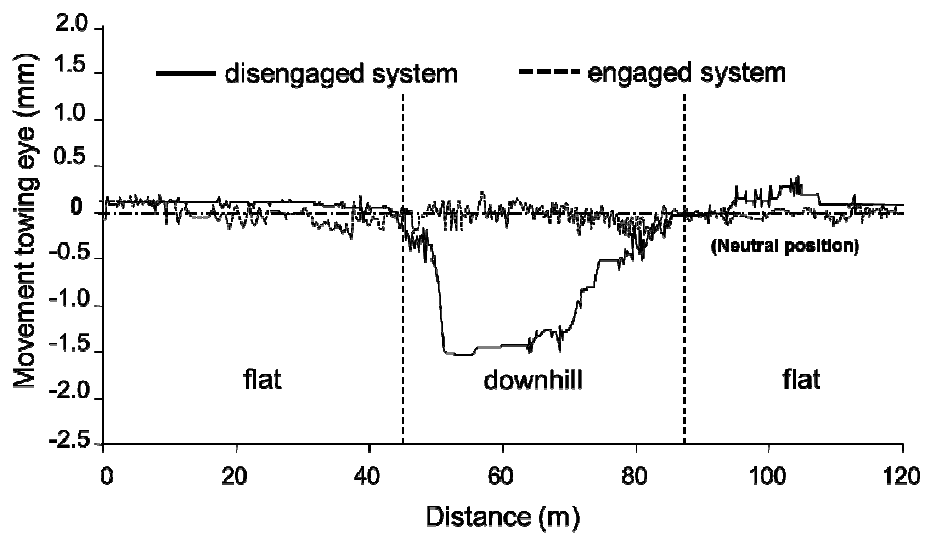
362 **Fig. 4.** Towing eye position with disengaged/engaged control system in a

363 downhill situation (trailer unloaded).



364

365 **Fig. 5.** Towing eye position with disengaged/engaged control system in an  
 366 uphill situation (trailer loaded).



367

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

370 **Table 1**

371 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 <sup>2</sup> )	3.00
Ground clearance	(m)	0.71
Tyres	550/45-22.5 ELS	
Loading capacity	(t)	12

372



373 **Table 2**

374 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

375