SIMULATION OF VEHICLE-OVERHEAD POWER SYSTEM INTERACTION ON ELECTRIC ROADS

Jenny JERRELIND, Lars DRUGGE, Annika STENSSON TRIGELL and Mikael NYBACKA

Department of Aeronautical and Vehicle Engineering
KTH Royal Institute of Technology
SE-100 44 Stockholm, Sweden

Received: November 5, 2012

ABSTRACT

Due to the upcoming lack of oil and the environmental problems that conventional internal combustion engines are causing, electric vehicles have gained a growing interest during recent years. One solution to improve the efficiency of the existing road network is to make use of electric roads equipped with an overhead power system, thereby allowing also long-distance truck and bus transports to be powered by electricity without the need of heavy, bulky and expansive batteries.

Providing electric power using an overhead power system has primarily been used in railway applications and only to some extent in road applications, for example in the case of trolley buses in urban areas. In this study, an overhead catenary system providing electric power to a long-distance truck by means of a pantograph mechanism that collects power through sliding contact with the overhead wire is analysed through simulation.

A model of a truck equipped with a pantograph is developed and its interaction with an overhead catenary system model is simulated using the finite element method. The current collection quality is evaluated by analysing the pantograph-catenary contact force variation during the influence of different disturbances such as road irregularities and contact wire vibrations due to multiple pantographs.

The study is an assessment of the possibility of using a conventional overhead power system developed for trains in a new context by providing power to long-distance road transports. The results show that the investigated disturbances influence the dynamics of the studied truck-pantograph-catenary system, nevertheless the contact force variation is within the allowed range according to the technical specifications for interoperability (TSI) for trains. It can be concluded that an overhead power system is a promising solution for a more environmentally friendly energy supply for trucks and buses at specific road sections.

Keywords: Electric roads, pantograph-catenary dynamics, future vehicle concepts

1. INTRODUCTION

As the number of vehicles in the world continues to increase as well as the amount of transported goods, it is important to reduce the environmental impact. Within the European Union (EU) a road map has been adopted in 2011 with the ambition to build a future competitive transport system that by 2050 will reduce the transport emissions with 60 % [1]. To make the transport system more environmentally friendly, solutions such as intelligent transport systems, new vehicle and infrastructure solutions and alternative energy/propulsion system needs to be developed.

The CO_2 emissions can for example be reduced by organizing the vehicle transports in platoons with short distances between the vehicles and thereby lowering the aerodynamic forces as well as increasing the capacity of roads [2]. Another way to reduce the use of fossil fuels is to, in a larger extent, use electricity to power the vehicles. However, the batteries of today are very heavy which result in inefficient solutions for long-distance transports. Creating electric road systems where the vehicles can get external power while driving reduces the need of expensive and bulky batteries [3]. Electric roads can be achieved by inspiration from some of the solutions used in the railway transport system, for example by induction (Maglev) or conduction (third rail and overhead catenary system).

In the presented work an overhead pantograph catenary system for trains is utilised for an electric road application. The advantage with using this solution for electric roads is that it is fast to integrate, it has been used for many years for trains and is thereby a well-tested technology and is not as expensive as induction solutions. Furthermore, the pantograph can connect and disconnect to the catenary while driving which simplifies entrance into and exit from electric road sections. Several research papers have been published regarding the dynamics of pantograph catenary systems on trains see for example [4-10].

The difference between the overhead power system on a train and a road vehicle is the fact that on a train the return current is sent through the steel wheels into the rail whereas for a road vehicle this is not possible due to the isolating rubber tyres. Instead a second parallel overhead contact wire is introduced to allow the current to flow back to the feeder station. The idea to use overhead power systems to electrify road vehicles has for example been used for trolley buses and on dumpers in the mining industry [11-13]. When the dumper is going up from the mine it connects to the catenary system with the pantograph to get a boost, going down, regenerative braking puts electricity back into the grid [13].

In order to have a good power distribution from the overhead power system to the vehicle the contact force variation shall not be too large in order to avoid contact loss and arcing. Challenges in the road application are among others the larger road irregularities compared to the rail application and that road vehicles have the possibility to drive with shorter distance between each other. The aim of this work is to model and analyse a truck-pantograph-catenary system to evaluate the contact force variation when different disturbances appear in the system such as road irregularities and contact wire vibrations due to multiple pantographs.

The outline of the paper is as follows; in section 2 the truck-pantograph-catenary model is presented followed by a section about the studied disturbances (section 3). In section 4 the simulation results are presented and analysed. Finally, some concluding remarks in section 5.

2. TRUCK-PANTOGRAPH-CATENARY MODEL

The investigated model includes a two dimensional finite element model of the pantograph-catenary system that is connected to a two degree of freedom model of a truck. The models are created with help of the finite element program ANSYS [14]. Below follows a more detailed description of the pantograph-catenary model and the truck model.

2.1 Truck model

It is assumed that the truck has one pantograph that is mounted on the truck chassis, see Figure 1. Since the pantograph frame is mounted on the chassis and not on the top of the cabin, the cabin dynamics have been ignored. Furthermore, the pantograph frame is mounted close to the front axle thereby the model is simplified by only including the vertical dynamics of the front axle of the truck. The resulting two degree of freedom linear model with its parameters settings corresponding to a truck is presented in Figure 2.

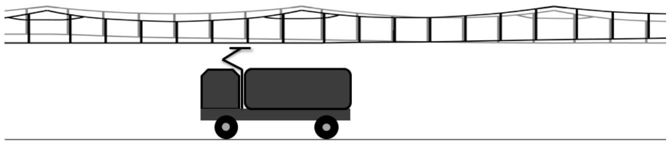
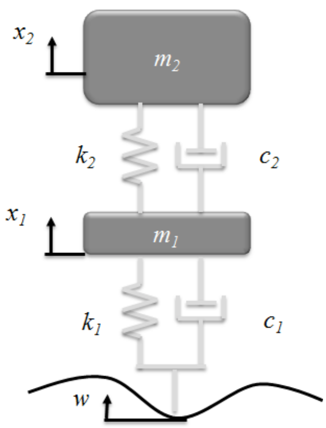


Figure 1. Illustration of the truck-pantograph-catenary system.

a)



b)

Parameter	Value	Unit
Sprung mass, m_2	3 400	kg
Unsprung mass, m_1	350	kg
Suspension stiffness, k_2	300	kN/m
Suspension damping, c_2	13	kNs/m
Tire stiffness, k_1	1 000	kN/m
Tire damping, c_1	1	kNs/m

Figure 2. a) The two degree of freedom truck model with road excitation *w* and **b)** the parameter settings for the truck model.

2.2 Pantograph model

The pantograph design considered in this study, Schunk WBL88X2, is today used for the Swedish high-speed train X2000, see Figure 3. It is modelled as a two degree of freedom lumped mass model, see Figure 4. In Figure 4 the parameter settings for the pantograph model is also specified.

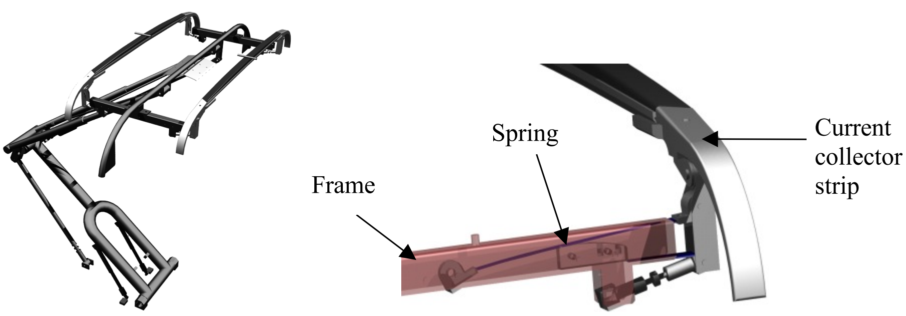
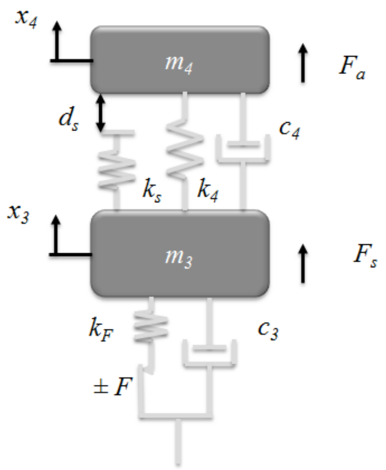


Figure 3. A Schunk WBL88X2 pantograph and its current collector strip suspension [8].

a)



b)

Parameter	Value	Unit
m_4	6.6	kg
m_3	19.7	kg
c_4	75.6	Ns/m
c_3	63.5	Ns/m
F_a	70	N
k_4	4.4	kN/m
k_f	1 000	kN/m
k_s	1 000	kN/m
F	17	N
F_s	70	N
d_s	0.03	m

Figure 4. a) The two degree of freedom pantograph model and **b)** the parameter settings for the pantograph Schunk WBL88X2.

2.3 Catenary model

The modelled catenary system is based on a stitch catenary system called SYT7.0/9.8 used by the Swedish Transport Administration on Swedish railways. The catenary wire, the stitch wire and the droppers are stranded wires having low bending stiffness and are built up of link elements. For the droppers link elements with bi-linear stiffness matrix are used resulting in a uniaxial tension-only element. The contact wire has a solid cross-section area and is modelled with beam elements. Since it is a two dimensional model it is assumed that the pantograph is excited at the midpoint of the current collector strip. Equivalent springs and masses represent the steady arms. The model consists of a section with ten identical spans with a span length of 60 m. The main parameters for the catenary system are specified in Table 1, for more details about the catenary model see [8]. The second parallel overhead catenary needed for the return current is included by assuming that both contact wires have the same excitation input and response, i.e. the properties in Table 1 is doubled in the present model.

Table 1. Main parameters for the catenary system SYT 7.0/9.8

Parameter	Value	Unit
Contact wire tension	9.8	kN
Catenary wire tension	7.0	kN
Contact wire area	100	mm^2
Catenary wire area	50	mm^2
Stitch wire area	35	mm^2
Dropper spacing	9	m
System height	1.3	m
Design speed	200	km/h

3. DISTURBANCIES

Contact force variations caused by different disturbances, for example road irregularities, contact wire irregularities and catenary vibrations due to multiple pantographs, can influence the current collection and thereby the functionality of the proposed system. In this work the dynamic influence of road irregularities caused by holes and bumps (see Figure 5) are investigated. Furthermore, when several vehicles are travelling along the same catenary system the pantograph motions might be influenced by each other through the interaction with the catenary system. Therefore the truck-pantograph-catenary system behaviour is studied when two trucks are running with different distances between each other.

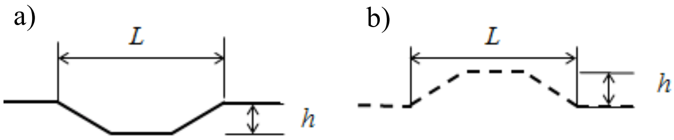


Figure 5. Illustration of studied road irregularities, **a)** hole and **b)** bump. The length L is divided into three equally long sections and the amplitude of the disturbance is h.

4. RESULTS

In this section results from the simulations are presented. The road disturbances are introduced either at the support pole in the middle of the catenary model (x = 300 m) or in the midspan of the subsequent span (in the middle between two support poles, x = 330 m). The road disturbance amplitude is 0.04 m and the lengths are varied to correspond to e.g. potholes and road settlements.

The quality of the current collection is important for the propulsion of the vehicle. According to the technical specifications for interoperability (TSI) for high-speed trains the standard deviation of the contact force is limited to be less than 0.3 times the mean pantograph force value [6]. In the simulations a static pantograph uplift force of 140 N is used.

Figure 6 show simulation results when a truck is running at 100 km/h on a flat road without irregularities as well as for a road with a 10 m long bump at a support pole. The contact force variation and the vertical displacements of the pantograph head, pantograph frame, the truck chassis (sprung mass) and the wheel (unsprung mass) as a function of position along the catenary system are shown. As can be seen for the truck, the sprung mass has several oscillations before the motion is damped out and the motion is enhanced compared to the unsprung mass response. The truck dynamics affects the pantograph motion and results in increased contact force variation.

The contact force standard deviation as a function of speed for the studied road irregularities introduced at the support pole is shown in Figure 7a) while in Figure 7b) the irregularities are introduced at the midspan. Also the results for a road without irregularities are included in the figures. On the flat road the contact force standard deviation is varying with speed and has a maximum at 100 km/h. Introducing irregularities with a length of 1 m results in general in a small increase compared to the results without disturbances. However, increasing the length of the irregularities to 10 m results in a much larger standard deviation. In Figure 7, the maximum contact force deviation (20.1 N) occurs at a velocity of 100 km/h for a 10 m long bump introduced at a support pole. When the irregularities are introduced at the midspan the effect is not as large and the standard deviation is larger for a hole, i.e. opposite compared to introducing the irregularities at the support pole.

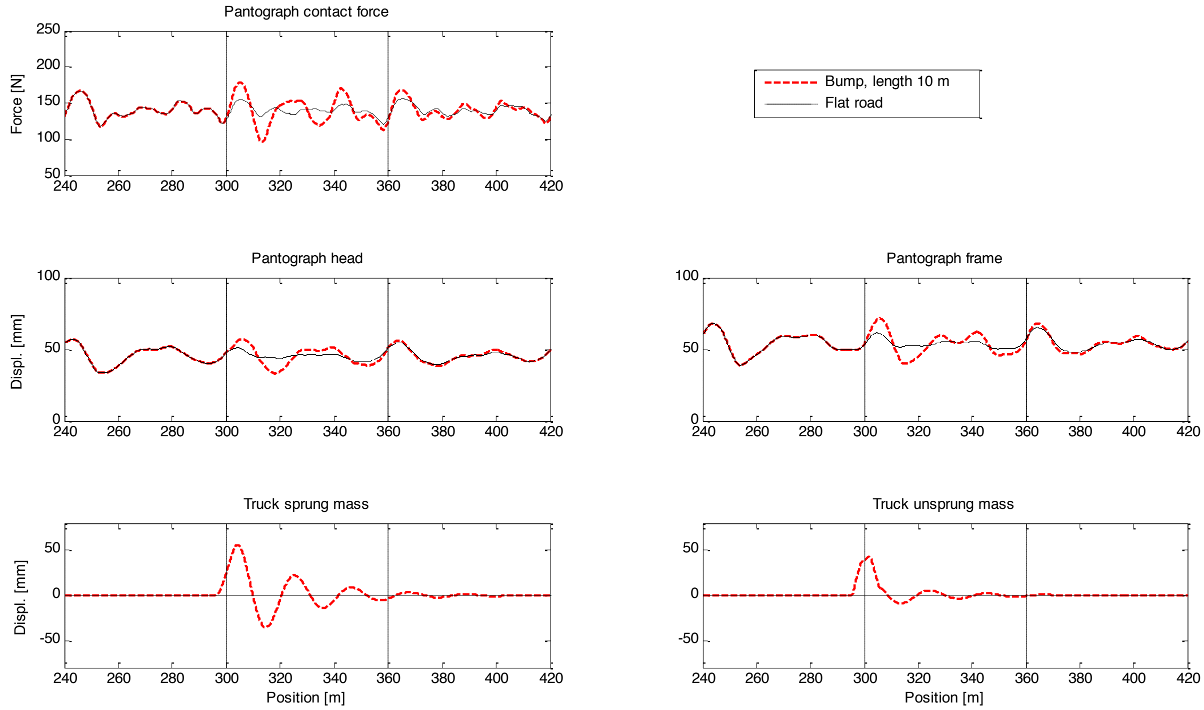


Figure 6. Pantograph contact force, pantograph displacements and truck displacements as a function of position along the catenary when a truck is running at 100 km/h. Solid line represents running on a flat road and dashed line represents when running on a road with a 10 m long bump at the support pole.

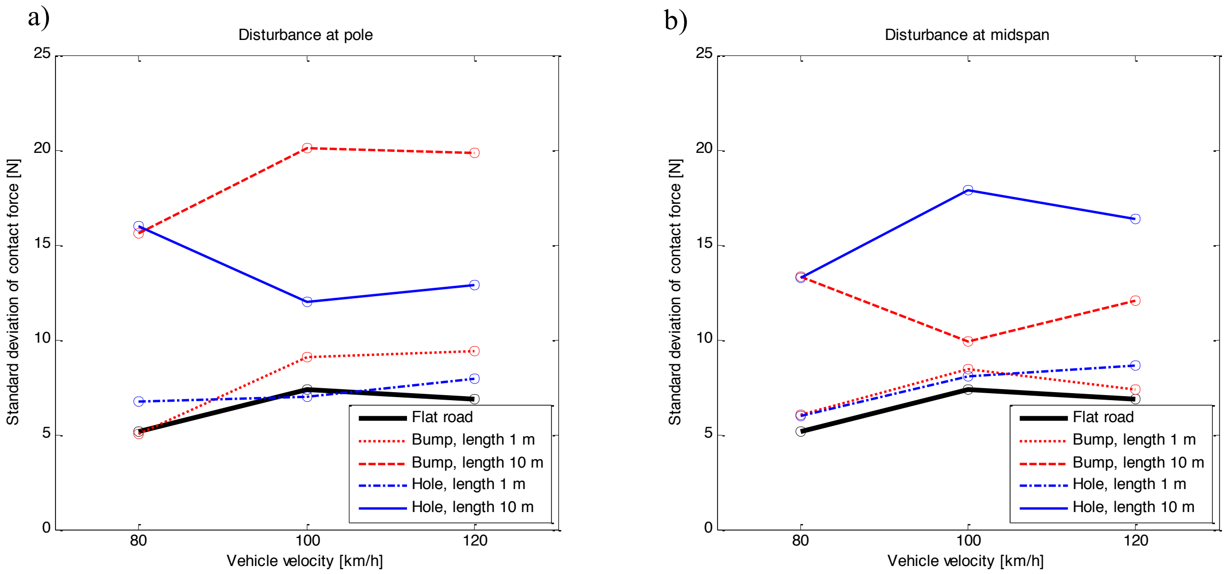


Figure 7. The contact force standard deviation as a function speed for **a)** flat road and road irregularities introduced at the support pole and **b)** flat road and road irregularities introduced at the midspan.

In Figure 8a) simulations of two trucks running with a distance of 45 m between the pantographs at different speeds are shown. Simulations are performed both for a flat road and a road with a 10 m long bump at a support pole. The results for the flat road show that the contact force standard deviation for the two pantographs are equal at 80 km/h while the trailing pantograph (P2) has higher standard deviation than the leading pantograph (P1) for increased speeds. When the bump is introduced the standard deviation of the contact force increases (in the same order as for a single pantograph, see Figure 7) and the value of the leading pantograph is larger than for the trailing. Figure 8b) presents the standard deviation of the contact force at a speed of 100 km/h for three different pantograph distances. It can be seen that on a flat road both pantographs have approximately the same contact force standard deviation for a distance of 60 m. When the pantograph distance is reduced the trailing pantograph standard deviation increases while the standard deviation of the leading pantograph is decreased. Introducing a 10 m long bump the trailing pantograph has the largest standard deviation of the contact force for pantograph distances of 30 m and 60 m, while at 45 m both pantographs have almost the same standard deviation.

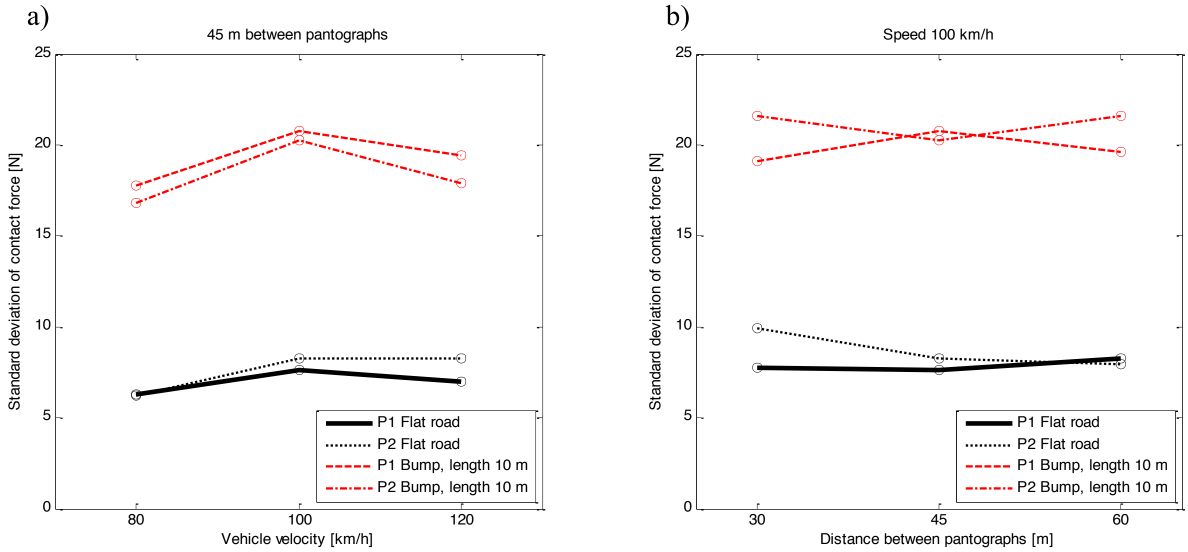


Figure 8. a) The contact force standard deviation as a function of speed for a pantograph distance of 45 m. The results are for flat road and a road with a 10 m long bump at a support pole. **b)** The contact force standard deviation as a function of pantograph distance at a speed of 100 km/h. The results are for flat road and a road with a 10 m long bump at a support pole.

Summarizing the results, a road irregularity of 1 m has a small influence on the contact force standard deviation (excitation frequency related to unsprung mass eigenfrequency), whereas when the length is increased to 10 m the standard deviation is larger (related to sprung mass eigenfrequency). For the investigated cases the maximum standard deviation of the contact force is 21.6 N (F_m = 139.7 N) which is for two pantographs combined with road irregularities (see Figure 8b), i.e. the standard deviation is well below the limit 41.9 N according to the TSI for trains.

5. CONCLUDING REMARKS

This work presents an assessment of the possibility of using a conventional overhead power system developed for trains in a new context, providing power to long-distance road transports. The results show that the investigated disturbances influence the dynamics of the studied truck-pantograph-catenary system, nevertheless the contact force variation is within the allowed range according to the technical specifications for interoperability (TSI) for trains. As a consequence it can be concluded that this is a promising solution for a more environmentally friendly energy supply for trucks and buses at specific road sections.

This study is based on combining existing design solutions for vehicle, pantograph and catenary in order to make a feasibility study. The pantograph-catenary system can be optimised for the considered road section, taking into account dynamic characteristics of different vehicles, status of road irregularities and practical solutions of how to handle road intersections, bridges, tunnels etc. Another important factor is the running speed where the studied pantograph and catenary are designed for high-speed trains while trucks and buses typically are designed for 100 km/h or less. This creates an opportunity to design cost efficient pantograph and catenary solutions tailored for electric road applications.

6. ACKNOWLEDGMENT

The financial support from the Centre of ECO^2 Vehicle Design and the Transport Research Environment with Novel Perspectives (TRENoP) are greatly acknowledged.

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