Dynamic Behaviour of Pantographs due to Different Wear Situations

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Abstract

The overhead power system supplying electricity to a train consists of the pantograph current collector and the overhead line equipment. Many of the parameters describing the dynamic characteristics of the pantograph vary during the lifetime due to wear, mounting conditions, weather etc. When evaluating the dynamic performance of the pantograph it is important to consider a realistic range of variation in key parameters.

To study this problem a three-dimensional pantograph model has been developed. It is based on the Schunk WBL88/X2 pantograph used for the Swedish high-speed train X2. The performance of the model of the overhead power system is analysed using a multibody dynamics program.

In this work, the influence on the dynamic behaviour of the pantograph, due to changes of key parameters in the head suspension, is investigated using numerical simulations and the methodology of factorial design. The ranges of variation in parameter values are determined from measurements on pantographs subjected to different wear situations.

Introduction

The main components of the overhead power system supplying electric power to a high-speed train are the pantograph current collector and the overhead catenary system. The catenary system consists of a contact wire supported by droppers which are suspended from a catenary wire, see Figure 1. The catenary wire is linked directly to the support poles, while the contact wire is linked to the support poles via steady arms. The contact wire is staggered from side to side in a horizontal plane to distribute the wear on the carbon collector strips of the pantograph.

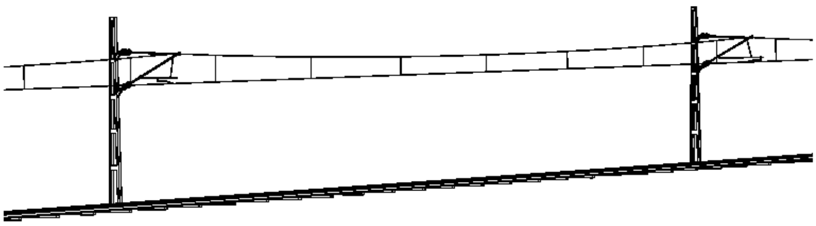

Figure 1. A simple catenary system.

The pantograph mechanism is mounted on the roof of the train. The essential features of the pantograph are the head assembly and the variable-height frame assembly, see Figure 2. The frame assembly raises the head assembly into forced contact with the contact wire.

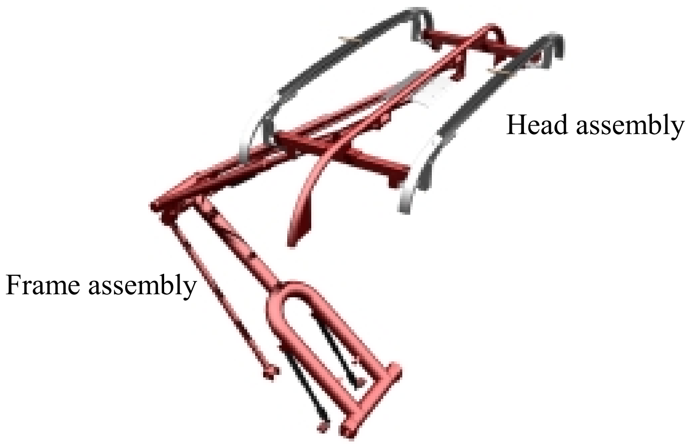

Figure 2. The Schunk WBL88/X2 pantograph solid model.

The head assembly consists of two carbon collector strips and a frame. The strips are connected to the frame via leaf springs and rigid links at each end according to Figure 3.

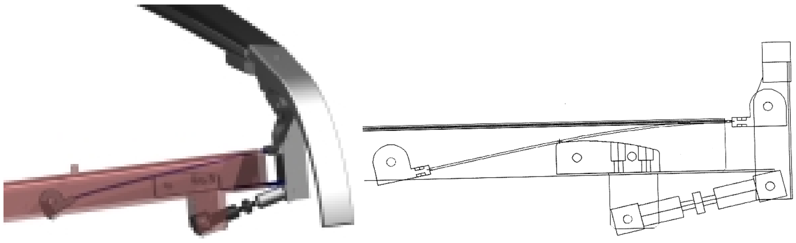

Figure 3. Subsystem of head assembly.

The pantograph and the catenary system are coupled via the contact force and they form a system that can oscillate. The maximum speed of the train is often limited due to increased dynamic effects in the overhead power system. The dynamic effects cause variations in contact force, and for satisfactory performance, the contact force must neither be so low that contact is lost nor so high that excessive movement, wear or mechanical damage occurs.

The parameters that describe the dynamic behaviour of the pantograph-catenary system can be derived from the physical properties of the components and their interaction. Many of the system parameters vary during lifetime due to wear, mounting conditions, weather etc. When evaluating the dynamic performance of the system it is important to consider the effects of realistic changes in key parameters.

The dynamic interaction between the pantograph and the catenary system has been studied by a number of researchers[1-6,9-13]. An overview of methods to describe the pantograph and the catenary system dynamics is given in Poetsch et al.[1]. The influence of characteristic parameters on the dynamic performance of the system has been studied in[2-6]. The effects of changes in pantograph stiffness and damping have been studied by Renger[2], Nowak & Link[3], Beadle et al.[4] and Willetts et al.[5]. The sensitivity of a typical overhead/pantograph system performance due to changes in key parameters in the catenary system is shown in Scott[6].

In this work, the influence on the dynamic behaviour of the pantograph, due to changes in head suspension key parameters, is investigated using numerical simulations and the methodology of factorial design. The ranges of variation in parameter values are determined from measurements on pantographs subjected to different wear situations. The performance of the model is analysed using a multibody dynamics tool. The aim is to study the dynamic behaviour of the pantograph due to variations in key parameters and their interaction.

Mathematical Model

A three-dimensional pantograph model has been developed. The model is a rigid body representation of the Schunk WBL88/X2 pantograph used for the Swedish high-speed train X2. The train has a design speed of 210 km/h. The pantograph is created in the MCAE-tool I-DEAS[7] as a solid model, see Figure 2, where the physical properties such as masses and inertias are derived according to the modelled design. The model is then exported to the MBS-tool ADAMS[8] in order to add the constraints, forces and spring-dampers.

Experiments have been performed in order to establish the main parameters in the head suspension. In Figure 4 the variation of spring force as a function of displacement are shown for a number of head suspensions subjected to different wear situations. A time history of the free oscillation of a subsystem in the head suspension is shown in the same figure.

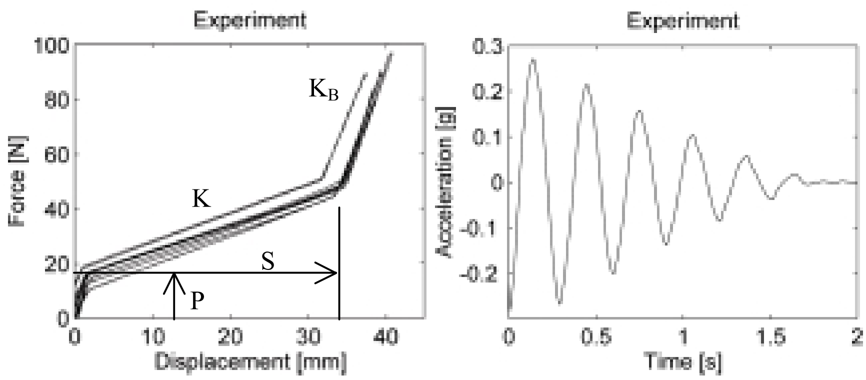

Figure 4. Examples of experimental results.

In the pantograph model, the spring stiffness is modelled as a preload, P, and a piece-wise linear stiffness given by the spring constants K, K_B

and the distance S according to Figure 4. The damping in the subsystem is approximated to be a combination of viscous damping, C, and friction damping, F. The damping of the main frame, C_F, is assumed to behave as a linear viscous damper.

Simplified catenary models have been used by some researchers[9-13] to study the dynamic behaviour of the overhead power system. Galeotti et al.[9] approximated the catenary system as a sinusodial displacement of the pantograph head. Brandani et al.[10] modelled the catenary system as a sinusodially varying stiffness. Huber et al.[11] used a variable stiffness and a stochastic force disturbance to represent the catenary. Nibler[12] approximated the contact wire to have constant mass per unit length. The wire was suspended to ground by a spring with sinusodially varying stiffness along the wire length. Kumezawa[13] extended the model by including a periodically varying contact wire mass along the wire length.

In this work, the catenary system is modelled as two lumped masses with mass m_c, acting on each carbon collector strip. Each mass is forced to move horisontally due to the zig-zag, and has one degree of freedom in the vertical direction. The mass of the catenary is connected to a spring with varying spring stiffness, $K_c(x)$. The catenary is assumed to have viscous damping, C_c. The stiffness variation of the catenary system is shown in Figure 5. The static height variation, Y(x), of the catenary system within a span is shown in Figure 6. The stiffness and height is representing the catenary characteristics along a span due to poles and droppers for the simple catenary system ST15/15 used in Sweden.

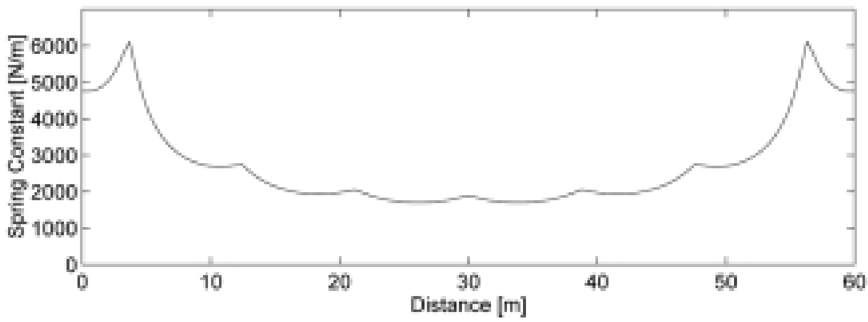

Figure 5. Catenary stiffness variation.

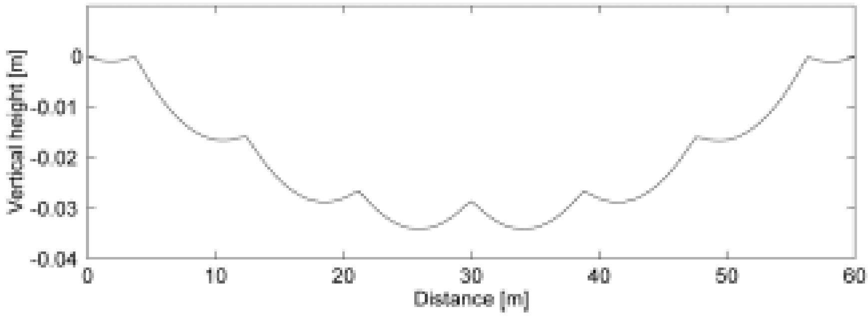

Figure 6. Catenary static height variation.

Simulation

The performance of the model of the overhead power system is analysed using the multibody system dynamics software ADAMS.

For the specific pantograph configuration shown in Table 1, analyses were performed within the speed range of 150 km/h to 300 km/h with an increment of 10 km/h.

Table 1. Parameters for a specific pantograph configuration.

Parameter		Value
Spring stiffness, K [N/m]		1000
End stop stiffness, K_B [N/m]		7550
Distance to end stop, S [m]		0.0335
Viscous damping, C [Ns/m]		2.6
Friction, F [N]		0.15
Frame damping, C_F [Ns/m]		63.5
Static uplift force, F [N]		50
Aerodynamic uplift force, F [N]	(v in km/h)	$0.00105v^2$
Contact wire mass, m_c [kg]		25
Contact wire damping, C_c [Ns/m]		5

The response of the front carbon collector strip suspension is shown in Figure 7. The figure show the time history of the vertical displacement in the right and left suspension.

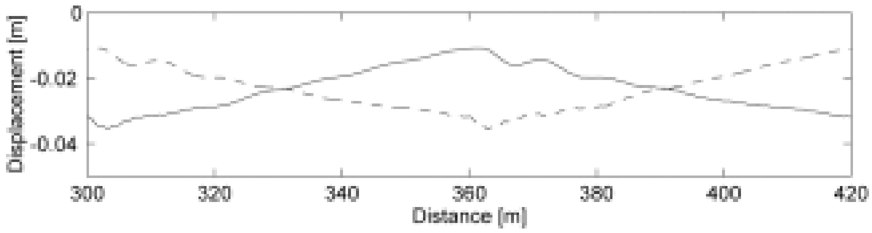

Figure 7. Vertical displacement of front carbon collector strip suspension as a function of time. Right (-) and left (--) head suspension.

Discussion among European railways has resulted in statistical analysis of the contact force as a good measure of current collection quality, Scott[6]. The possibility of contact loss can be evaluated by the criteria,

$$F_m - 3 \cdot \sigma < 0, \qquad (1)$$

where F_m is the mean contact force and σ is the standard deviation. Figure 8 show results for the system described in Table 1, as a function of speed. The solid line represents the sum of the mean contact forces between the two carbon collector strips and the catenary. The dashed lines show the dynamic range of the contact forces. The dynamic range is represented by $\pm 3\sigma$.

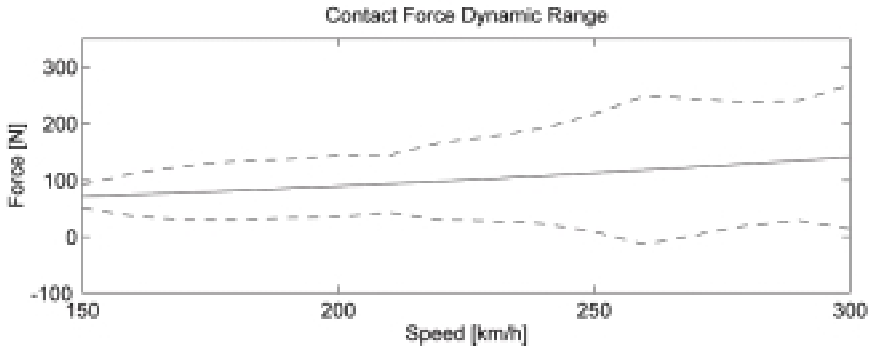

Figure 8. Mean force (-) and contact force dynamic range (--).

Ranges of parameter values of the head assembly are shown in Table 2. The values are determined from the measurements of new, used and worn pantographs, see Figure 4.

Table 2. Range of head assembly subsystem parameters.

Parameter	Min (-)	Max (+)
Viscous damping, C [Ns/m]	1	10
Spring stiffness, K [N/m]	950	1250
Friction, F [N]	0.1	1
Distance to end stop, S [m]	0.03	0.04

In order to study the dynamic behaviour of the pantograph due to variations in the parameters in Table 2 and their interaction, a 2^4 factorial design[14] methodology was used. By performing a factorial design study, few runs per factor is needed to indicate major trends and directions for further analysis. It also indicates the interaction effects between the studied parameters. The factorial design study was performed for a speed of 220 km/h and the system parameters shown in Table 2. The result of the study is shown in Table 3. The simulations were run for 12 spans and the statistical characteristics were evaluated for the two intermediate spans.

The criteria for evaluation was the sum of the standard deviations of the contact forces between the two carbon collector strips and the catenary. These values are shown in the right column of Table 3. The last row show the main effects of the parameters and their interaction. The damping, C, and the friction, F, are as seen, the two main variables effecting the system performance. It can also be seen that the interaction of these two parameters are important. As a consequence, the interacting variables must be considered jointly.

To evaluate the effects of these two parameters on the dynamic behaviour of the pantograph, simulations were run for the speed range of 150 km/h to 300 km/h with an increment of 10 km/h. The pantograph configuration was according to Table 1 except for values for C and F. Figure 9 show the dynamic range of the contact forces. The dynamic range is represented by $\pm 3\sigma$. In the figure, the dashed lines show results for C = 1 Ns/m and F = 0.1 N, i.e. the minimum values from Table 2. The solid lines show results for parameter values according to Table 1. The dash-dotted lines show results for C = 10 Ns/m and F = 1 N, i.e. the maximum values from Table 2. The vertical line in the figure is indicating the X2 design speed.

Table 3. Factorial design result.

	C	K	F	S	C x K	C x F	C x S	K x F	K x S	F x S	C x K x F	C x K x S	C x F x S	K x F x S	C x K x F x S	Values
1	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+	28
2	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	17
3	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-	28
4	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+	16
5	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-	16
6	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+	14
7	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+	14
8	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-	13
9	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-	33
10	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+	17
11	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+	55
12	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-	22
13	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+	17
14	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-	15
15	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-	22
16	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	17
Values	-10	4	-11	6	-3	8	4	-3	5	-3	2	-2	3	-2	2	

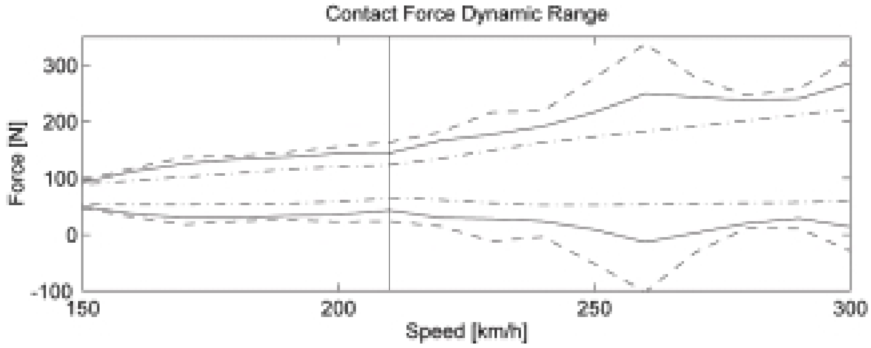

Figure 9. Contact force dynamic range. (--) C = 1 Ns/m, F = 0.1 N,
(-) C = 2.6 Ns/m, F = 0.15 N, (-.) C = 10 Ns/m, F = 1 N.

Discussion and Conclusions

The aim of this study is to investigate the effects of changes in key parameters in the head suspension on the dynamic behaviour of the pantograph, due to different wear situations. To study this problem a three-dimensional pantograph model has been developed. The catenary is represented by two lumped masses connected to springs with variable stiffness and equilibrium heights. The range of variation in parameter values are determined from measurements. The influence of variations in these parameters is investigated using numerical simulations and the methodology of factorial design.

It is shown that the most important parameters are the viscous damping and the friction of the head suspension, as shown in Table 3. In Figure 9 it is shown that for speeds up to the design speed, the dynamic range of the contact force can be doubled, depending on the actual state of the suspension. For higher speeds, the range of the dynamic forces can vary with up to a factor of three. When evaluating the possibility of contact loss it is seen that two of the three head suspensions shown in Figure 9 have increased risk of contact loss with higher speed.

The proposed methodology has been proved to be a powerful tool when investigating the effects of different wear situations on the dynamic behaviour of a pantograph. The results can be used to evaluate maintenance criteria for pantographs.

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