

# **PANDA: a friendly CAD tool for pantograph design and testing**

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## **Abstract**

An interactive, user-friendly and graphically oriented toolbox for pantograph testing and design is presented in this paper. The pantograph structure can be chosen between four different classes: asymmetric, symmetric, scissors-shaped and seesaw-shaped pantograph. The first two classes include traditional as well as active solutions. The toolbox realizes a first software aid for performance evaluation of traditional and/or innovative pantographs.

## **1 Introduction**

For high-speed trains (over 220 km/h) a regular current pick-up in pantograph-catenary systems is a hard task to be satisfied. The effects of the interaction between the overhead line and the moving pantograph are magnified at high speed; in order to reduce the losses of contact or excessive oscillations of the catenary, standard current pick-up equipment must be modified. In the past a lot of simple and ingenious solutions have been adopted in order to improve the performance of the pantograph-catenary system. Now there seems to be a general accordance that the design of high performance pantographs offers the best potentiality for the future in terms of costs and optimal current pick-up. After the initial studies of Beadle [1] and Eppinger [2] proposing new configurations of hydraulically servo-actuated pantographs, many researchers devoted their efforts on active pantographs [3-5]. In spite of

the great variety of proposed solutions, a major problem to overcome is the practical application of the theoretical (or simulated) results. Every solution must satisfy the requirements of safety, reliability, simplicity and must be technically as well as economically viable. The feasibility of an active pantograph has to be tested by an accurate CAD tool especially if innovative design solution is proposed. The proposed toolbox for a software preliminary evaluation of innovative pantographs was named PANDA, an acronym for PANTograph Design Assistant.

## 2 Modelling the contact

The catenary-pantograph dynamic modelling is extremely complex and even finite element analysis cannot correctly simulate the real behaviour. Therefore in the toolbox the simplest possible model meeting the objective to evaluate the dynamic behaviour of the pantograph-catenary system will be considered. A simplified model of the catenary based on the well-known string model [7], suitably modified to consider the high frequency component due to the droppers has been considered (see [4] for a detailed analysis).

The contact line interacting the pantograph is modelled by a rigid slender bar connected to a fixed point by a linear spring and damper. The bar is allowed to rotate around a barycentric axis in the longitudinal plane with respect to the contact line. Such rotation is contrasted by the axial tension  $T$  (Figure 1)

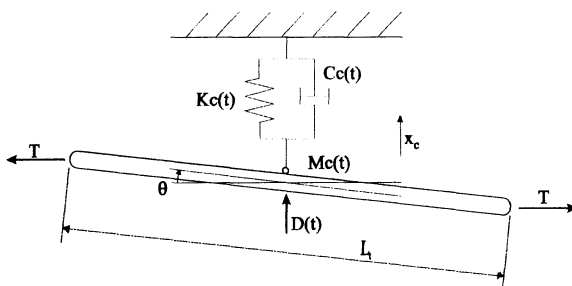


Figure 1: Two degree of freedom catenary model.

It must be remarked that the rotational motion is not considered in the models previously presented in literature to the authors' knowledge. Its introduction provides the basis for an effective analysis of the physical phenomena due to friction and it is important especially in the case of pantographs with multiple contact shoes. Consider now the pantograph

model. For instance the case of asymmetric dual-stage pantographs considered in the toolbox is shown in Figure 2. A peculiarity of such a pantograph is the presence of two contact shoes in order to minimise the losses of contact and to reduce the dimensions of the single collector strip. The dynamic equations for the whole nonlinear model are derived using the Lagrangian approach.

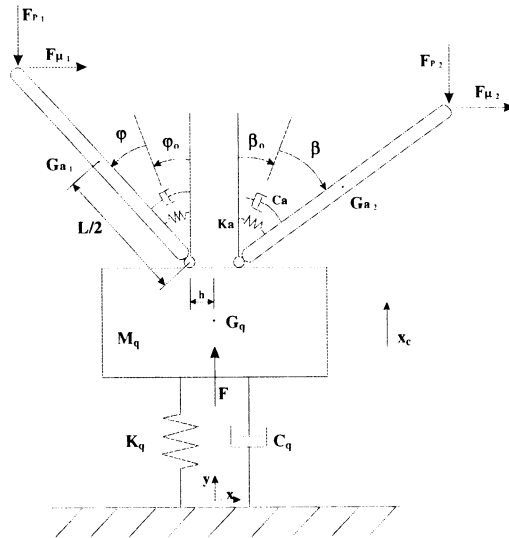


Figure 2: Model of the asymmetric pantograph.

The toolbox considers the case of active control. A practical implementation of the active pantograph is suggested and denoted as ‘wire actuated control’ ([7], [8]). In Figure 3 a schematic drawing of the wire-actuated control is shown. The control action is exerted on each upper arm through a wire. The wire can wind or unwind around a pulley dovetailed to the shaft of an electric motor located on the roof of the vehicle. The wire acts only in traction, i.e. the contact force can be regulated if and only if the wire is tight. In order to satisfy such condition the contact force provided by the passive mechanism is set to a higher value than in the traditional case: the control action of the wire will regulate the contact force to the desired level, pulling down the upper arms. The speed of response of the control system is very high: only the upper arms has to be moved, reducing the mass to be moved with respect to the case of the control force acting on the linkage frame and moving the mass of the whole pantograph.

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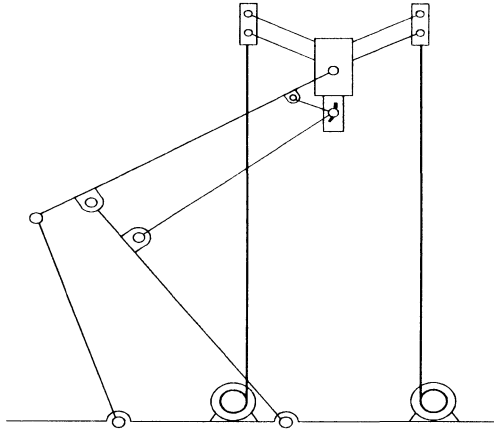


Figure 3: Wire actuated control scheme.

A brushless DC motor with low inertia and small electro-mechanical time constant could be the simplest choice for the electrical actuator.

### 3 PANDA Toolbox

The software package was developed using MATLAB<sup>®</sup>, version 4.0 on a personal computer. The minimal configuration, using a DOS-based architecture, is a PC 386 with math co-processor and 4Mb RAM, running Windows 3.1.

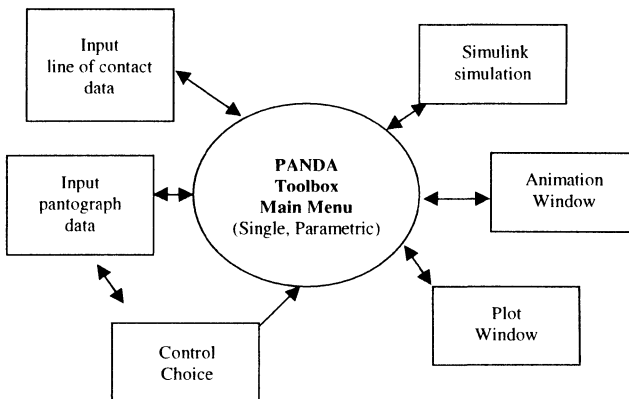


Figure 4: PANDA toolbox options.

By running on top of Windows, MATLAB® takes advantage of several graphical facilities that can be used to build a suitable graphical user interface (GUI). In Figure 4 a functional scheme representing the PANDA options is shown.

PANDA can be run as an m-file, with the call 'panda' in the Matlab command Window. The execution starts with the presentation of a figure-window containing "push-buttons" corresponding to the analysis to be performed. A preliminary option of the toolbox allows the user to select a single or a parametric simulation. The single simulation has fixed parameters; in the case of a parametric simulation the performance of the system is analysed whenever one parameter of the pantograph is varying within a bounded set of values. Such option is particularly attractive for design purposes.

The program is hierarchically structured: the main menu allows the user to choose the pantograph structure between the following classes:

1. asymmetric pantograph;
2. symmetric pantograph;
3. scissors-shaped pantograph;
4. seesaw-shaped pantograph.

In Figure 5 the four classes are drawn.

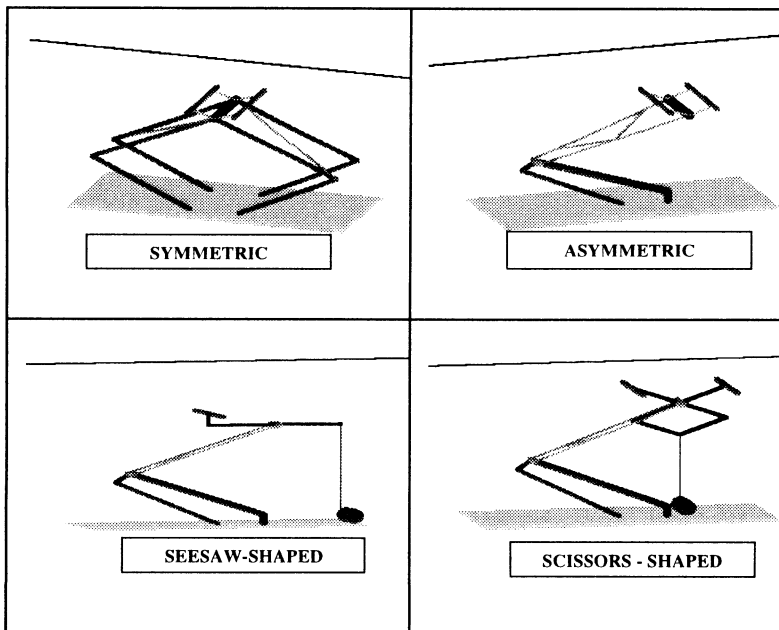


Figure 5: Pantograph choice.

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It must be remarked the presence of the control system (motor plus wire) in the cases 3 and 4.

By clicking on the button corresponding to the chosen class, new window menus are activated. An information button ('INFO') and a return to main menu ('MAIN MENU') are available on the bottom of the main menu window and of each sub-menu window.

When the input of the parameters is complete, the package starts with the dynamic simulation using Simulink (Simulation button).

The input data are automatically passed to the Simulink representation of the selected controlled (or uncontrolled) pantograph. Of course all the properties of the Simulink environment are retained and the user can for instance add 'Scope' blocks to monitor variables of interest during the simulation, or modify any parameters in the Simulation menu including the integration method. After simulation the plot window or the animation window can be called. On the right of such windows, a pop-up menu is available. The user can select among the variables transferred from Simulink to Matlab by 'To Workspace' blocks and plot the variables of interest. The zoom function is always activated using the mouse. A mouse driven crosshair option can be activated (such option disables the zoom function) in order to display the current position of a selected point on the graph. Consider for instance the case of the asymmetric pantograph. In the following figures (Figures 6-11), an example of a possible sequence of the toolbox windows is shown.

ASYMMETRIC PANTOGRAPH	
<b>Simulation parameters</b>	
Start time	0 s
Stop time	5 s
Step	0.0001 s
Sampling frequency	100 Hz
<b>INFO</b>	
<b>MAIN MENU</b>	
<b>CATENARY</b>	
<b>MODEL</b>	
<b>SIMULATION</b>	
<b>ANIMATION</b>	
<b>PLOT</b>	
<b>LOAD</b>	
<b>SAVE</b>	

Figure 6: Case of asymmetric pantograph.

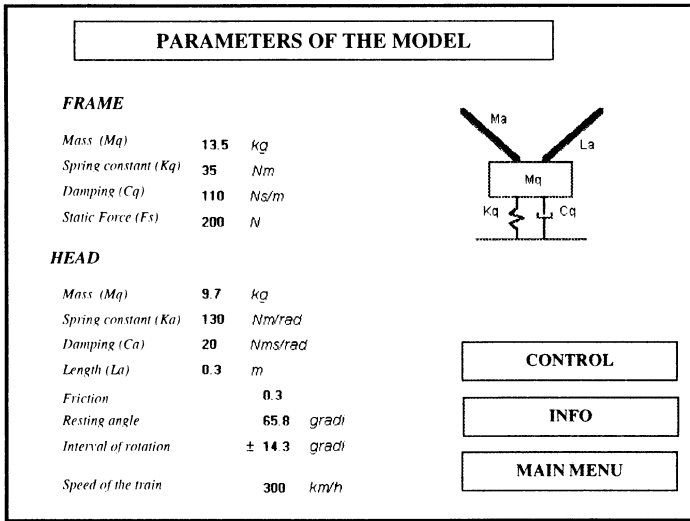


Figure 7: Data for modelling the asymmetric pantograph.

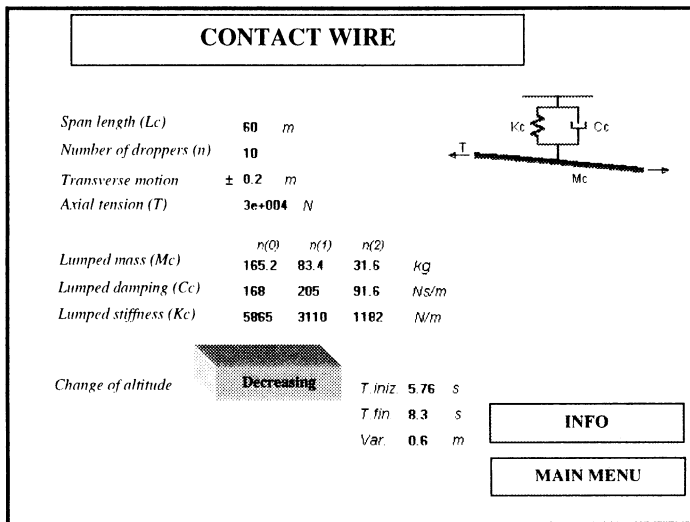


Figure 8: Data for modelling the contact line

In the Animation window the interaction between the pantograph and the contact wire is visualised. The animation is composed of 3 phases:

- building the 3-D model of the pantograph;
- simulation of the model
- starting the animation.

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With regard to phase a), a suitable reference frame has been fixed. The pantograph is schematised by rigid bars, identified by the coordinates of their extremities with respect to the reference frame. The animation is executed only when the simulation phase has been run down.

CONTROL WINDOW

CONTROL STRATEGY

Two wires

CONTROLLER A

$K_p$  1  $F_{nom}$  100 N  
 $K_i$  1

CONTROLLER B

$K_p$  1  $F_{nom}$  100 N  
 $K_i$  1

BACK

INFO

MAIN MENU

Figure 9: Control window. Active pantograph case.

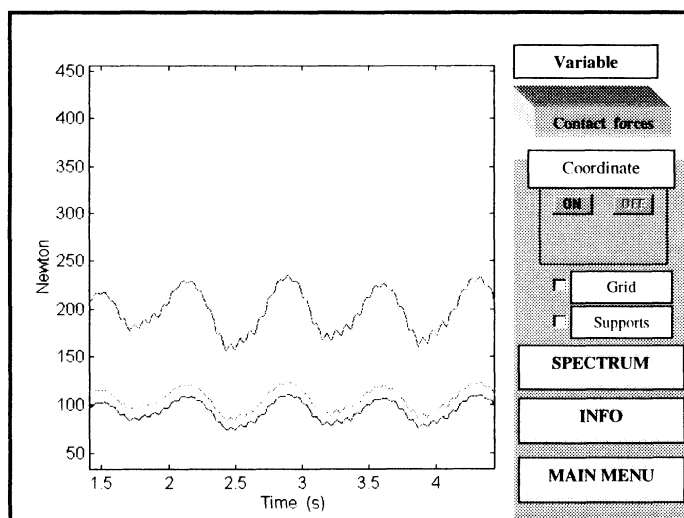


Figure 10: Plot window



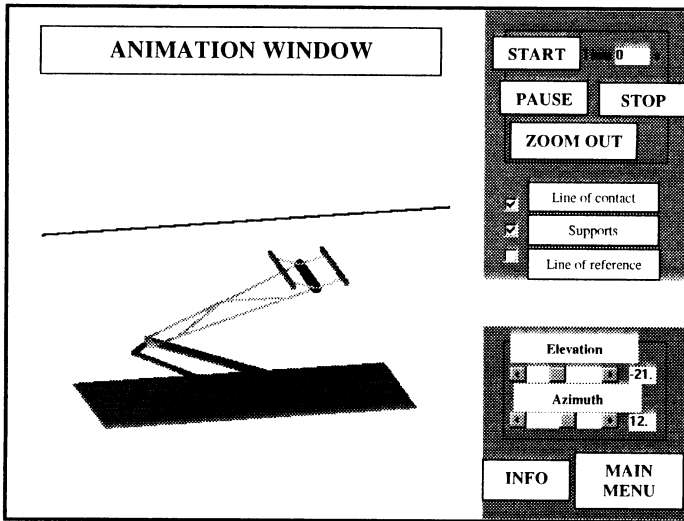


Figure 11: Animation window

At the end of the simulation phase the output variables (versus time) are available and at each sampling time  $t_k$ , the location of all bars and of the contact line can be computed.

In such a way the graphic objects are redrawn and the frame of the 3-D model at  $t_k$  is obtained. The animation effect is due to the sequential visualisation of the frames. The effect of the relative motion between the pantograph and the contact line is obtained by fixing the pantograph in the middle of the visual window and by moving the line. At each frame a line length equal to a span length is drawn; the supports are moving across the screen in order to visualise the relative motion.

## 4 Conclusions

In this paper a graphical design tool for the pantograph-catenary system is presented. The used model for the contact wire is quite simple, but retaining most measured effects of the pantograph-catenary interaction. The PANDA toolbox realizes a useful first software aid for design and testing of traditional and/or innovative pantograph structures.



## Acknowledgement

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