PACIFIC PROJECT

Final Report

I. INTRODUCTION

In the framework program INTERREG IV, ESIEE Amiens (Graduate Engineering School, FR), UPJV (Université de Picardie Jules Verne, FR) and UoB (University of Brighton, UK) have developed a pantograph-catenary interaction software under the PACIFIC project (Pantograph Catenary Interaction Framework for Intelligent Control) from 2009 to 2011.

The pantograph and the catenary together form a dynamically coupled vibrating system affecting each other through the contact force (Fc). The Fc is composed of the static force that is called lift force and the dynamic force which depends on the running speed and the vibrational behavior of the catenary – pantograph system.

The major source of vibration (interaction between the pantograph and the catenary) is the spatial stiffness variation of the catenary along the line (span) which is not constant but changes regarding the distance from the support pole. Its value is minimum in the middle and is maximum near the support tower. Additionally, the Contact wire static position is not perfectly align with the railway plane and the span stagger (effect of 20 cm in both directions respect to the central point of the contact stripes) have an impact on the interactions.

II. CATENARY MODELS

Two models are considered, the static catenary and the dynamic catenary models.

II.1 STATIC CATENAY MODEL

The simplified railway overhead contact line model (lumped model) considers variable parameters, $k_c(t)$ the static variation of stiffness, $m_c(t)$ the mass and $c_c(t)$ the damping along a span according to the pantograph position along the catenary. This model emulates the first modal behaviour of the catenary system.

II.2. DYNAMIC CATENARY MODEL

A precise model of catenary considers all nonlinearities which exist in each part of the catenary. This model represents the assembly of each component such as droppers, insulators, registration arm, contact wire and registration wire (Fig. 1).

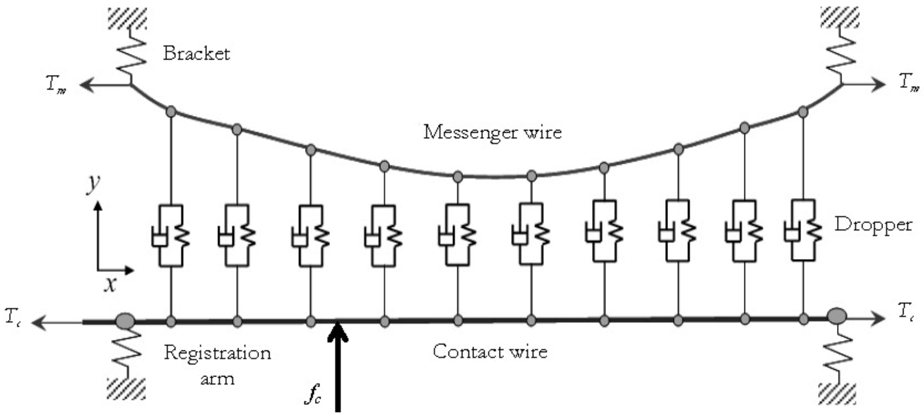


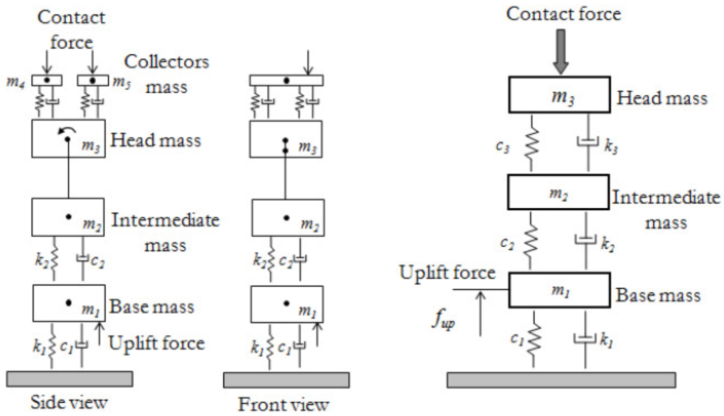
Figure 1: Model of catenary system represents the mass summed for half of the dropper and its clamp represents the mass of registration arm

The formulation of the dynamics of the catenary is formulated according to the beam models (Euler-Bernoulli-Timoshenko beam) taking into account the bending stiffness of the wire and the effects of shear deformation and rotary inertia.

We will refer to this model as 2D Euler-Bernoulli- Timoshenko model or just 2D FEM (Finite Element Method).

III. PANTOGRAPH MODELS

The pantographs in SIMPAC are actually represented by standard models, the 1DOF and 2DOF in Figure 2.



Model 2D: model 1D with rotational movement of the strips and elasticity of upper frame

Model 1D: Linear mass-spring-damper modeling

Fig.2: 1D and 2D Modeling of the pantograph

Referring to EN50138 standard, the mathematical equations are the following:

$$m_2\ddot{z}_2 + c_2\dot{z}_2 + c_1\left(\dot{z}_2 - \dot{z}_1\right) + k_2 z_2 + k_1\left(z_2 - z_1\right) = F_2$$

$$m_1\ddot{z}_1 + c_1\left(\dot{z}_1 - \dot{z}_2\right) + k_1\left(z_1 - z_2\right) = F_c$$

Where the subscript 1-2 stand for:

- $_1$ collector head
- $_2$ base frame.
- m is the mass
- k is the stiffness
- c is the damping
- F2 is the external actuator force
- F_c is the contact force
- z is the vertical coordinates of the pantograph parts.

IV. COMPARISON TO STANDARD

Validation: EN50138-2000

Using the previous mathematical model it's possible to achieve the following results:

	Reference (EN50138)	Simulation results			Reference (EN50138)	Simulation results		
		Simple	Lumped	E.B.T.		Simple	Lumped	E.B.T.
Speed [km/h]	250				300			
F_m[N]	110 to 120	116.66	116.49	116.00	110 to 120	116.69	116.49	117.8
σ [N]	26 to 31	24.33	5.56	26.10	32 to 40	37.66	6.06	36.3
Statistical maximum of contact force [N] (F_m+3σ)	190 to 210	189.65	133.18	194.20	210 to 230	229.68	134.67	226.7
Statistical minimum of contact force [N] (F_m-3σ)	20 to 40	43.67	99.81	37.70	-5 to 20	3.70	98.31	9.00
Actual maximum of contact force [N]	175 to 210	161.75	125.90	165.1	190 to 225	180.23	125.77	213.2
Actual minimum of contact force [N]	50 to 75	83.27	108.49	53.1	30 to 55	68.96	107.00	50.60
Maximum uplift at support [mm]	48 to 55	26.10	44.80	56.00	55 to 65	34.00	44.00	62.00
Percentage of loss of contact [%]	0	0	0	0	0	0	0	0

This table shows that among all developed models, the FEM (Euler-Bernouilli-Timoshenko) is the most reliable compare to the standard EN50138-2000.

IV. PACE (Pantograph And Catenary Executable) GUI USER MANUAL:

The first screen (Fig.1) of the PACE interface is realized by means of three main different area:

- Simulation Data: where the all the simulation parameter used along the simulation can be set up;
- Simulation: is a button that allow to perform the desired simulation of the simulink files;
- Post processor: after the simulation is done it is possible to make a simple standard analysis of the output.mat simulation data.

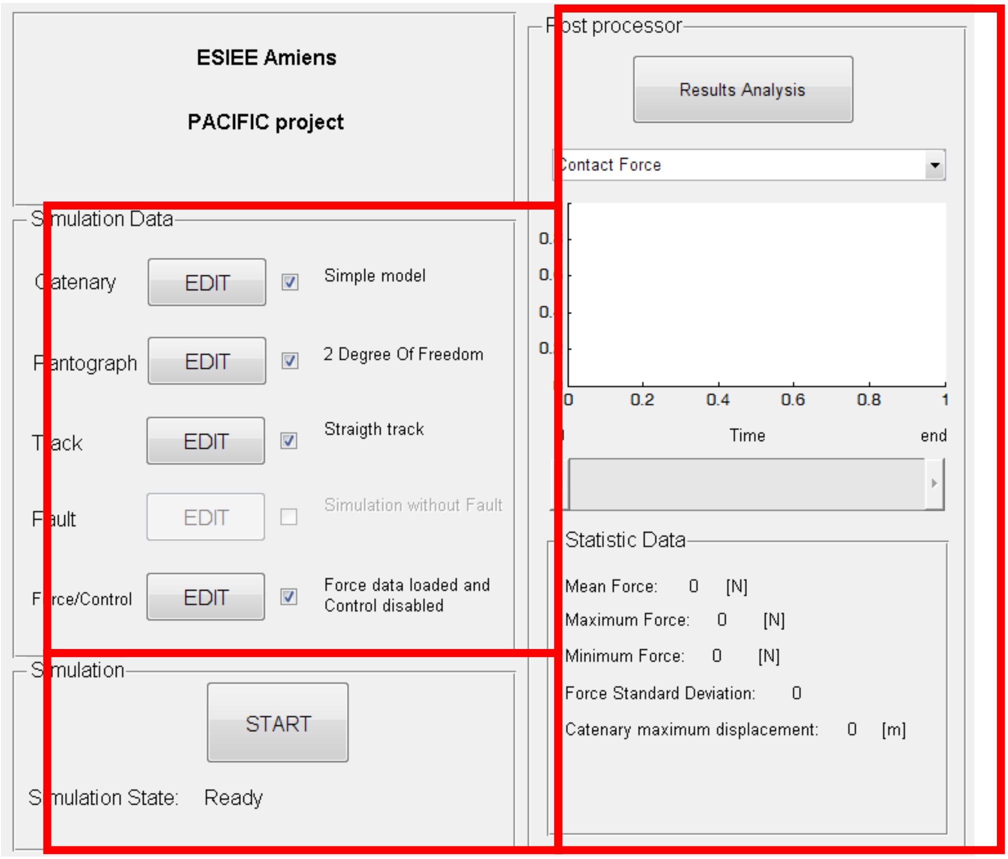


Figure 1: PACE Front Panel window interface.

1. Simulation data:

Simulation data windows (Fig.2) is mainly realized in four different parts:

1. Data label: label of the data group that can be set-up;
2. Edit button: button that allow to acces the data set-up windows;
3. Check box: is a flag that show a √ when the relative data is correctly set up;
4. Text data: label that identify wich kind of selection has been take for the actual simulation.

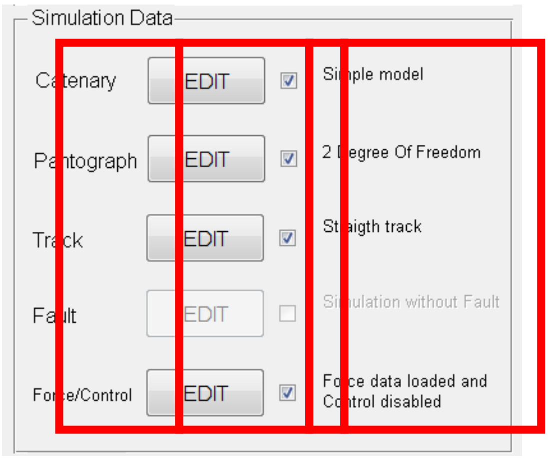


Figure 2: Simulation data box on Front Panel window

Using the Edit button several windows can be open in order to introduce all the parameter values.

1.1. Catenary panel:

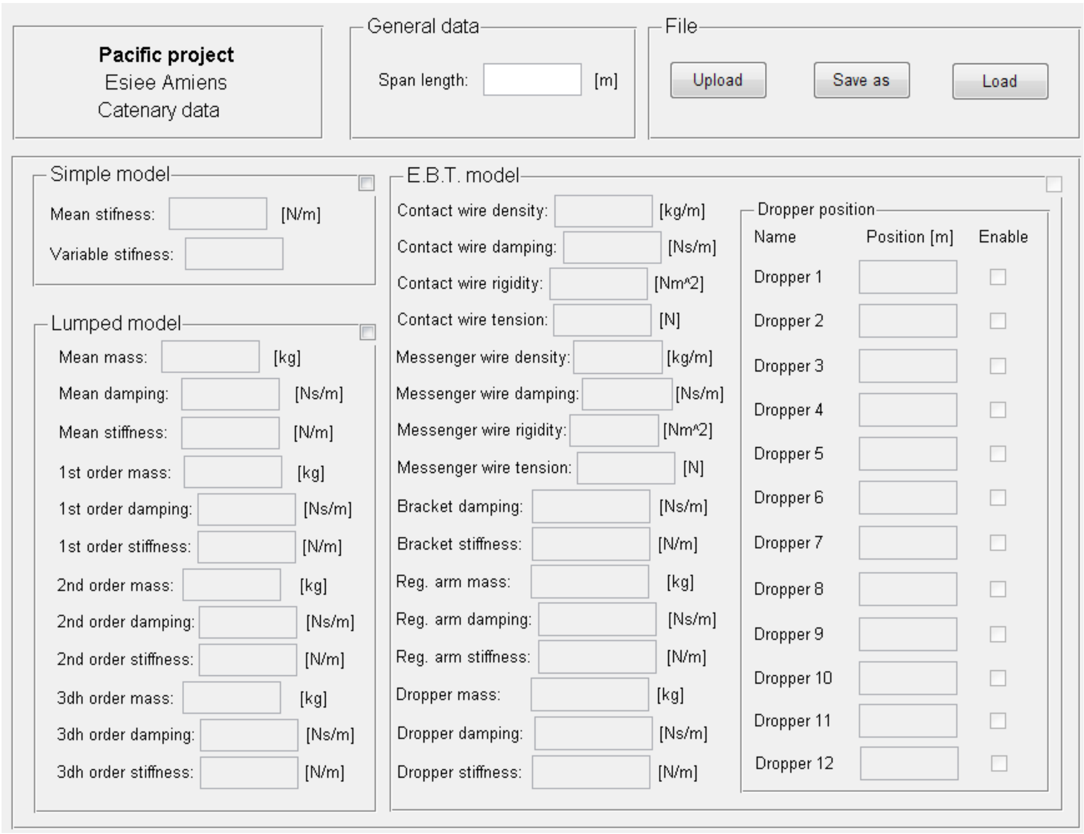


Figure 3: Catenary panel window

Inside this window several parameter can be set in order to perform simulation with different catenary mathematical modela and with different parameters. As visible three different version have been realized:

- Simple model: this model is realized by taking into account only static stiffness variation along the span, thus neglecting stiffness variation between the vertical droppers, with the knowledge of the train position Pos it can be approximated by means of a single variable spring stiffness (k). In order to use this model the user has only to select the check box on the up-right corner of the simple model box and insert the desired value of the length span L, the mean value k_0 and the variable stiffness α.

  During our previous study we have evaluated this value by means of analysis on a FEM catenary model based on the EN50318; this value can be loaded by pressing the load button and selecting simple catenary.mat file.

- Lumped model: this model take into account the variation of mass m_c, damping c_c and stiffness along the span.

  Even for this model a predefined set of data, obtained from the FEM analysis of the EN50318 catenary, is available inside the lumped_catenary.mat file

- E.B.T. model: is the Euler Bernoulli Timoshenko model that has still to be implemented inside this GUI window.

On the upper rigth part of the GUI window tere is the “File” box where three button are available:

- Upload: by pressing this button all the data of this window will be stored inside the temporary_data.mat in order to be available for the pantograph/catenary simulation;
- Save As: this button allow the operator to save the written data of the windows over a desired file;
- Load: allow the operator to load a predefined set of parameter for the desired simulation.

1.2.Pantograph panel

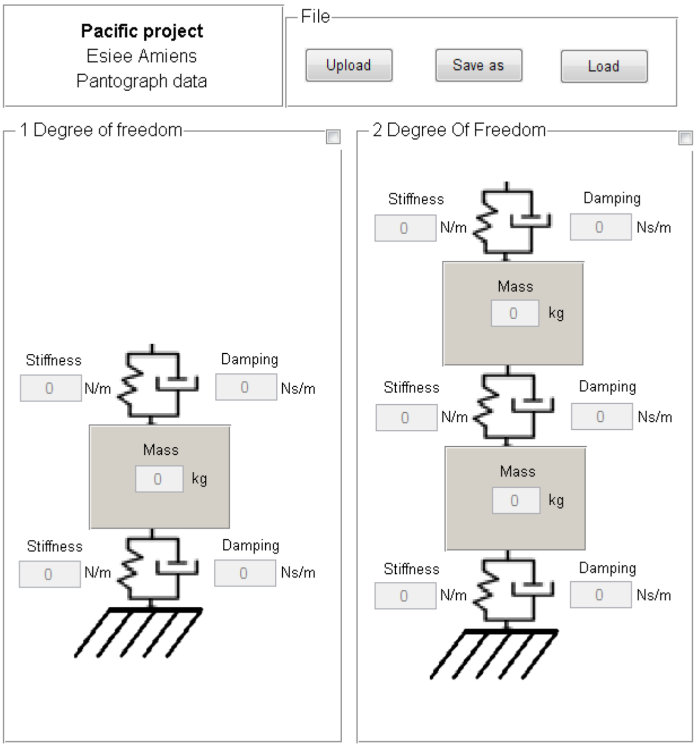


Figure 4: Pantograph panel window

Inside this window both the 1 and 2 degree of freedom model of the pantograph can be selected and customized in order to be used inside inside the simulation.

In order to choose wich one of the two model has to be used inside the simulation the respective up-rigth check box have to be enabled. After that it is necessary only to insert the desired value of mass, damping and stiffnes in the rigth position like it is briefly represented inside the respective box.

For both the two model a first set of parameter can be loaded by opening, inside the Pantograph panel, the single_degree_pantograph.mat or the EN_pantograph.mat wich is based on the parameter given by the standard reference EN50318.

Even inside this window there are the same “Upload”, “Save as” and “Load” that works just like said before for the Catenary panel.

1.3.Track panel

Inside Track panel window it is possible to insert all the information concerning the track to be followed by the pantograph. Each simulation is performed untill the train reach the end of the track as specified inside this window.

Looking the Track panel window on the up-rigth corner the same “File” box can be found with the same three button (Upload, Save as, Load) that works as explained before for the Catenary and Pantograph panel.

In the central part of the window only one type of track is available: the straigth one, due to the fact that only monodimensional model od pantograph/catenary have been implemented untill now.

Afrter having select this type of track, by checking the up-rigth check-box, it is possible to define the total length of the simulation to be done, the initial position of the pantograph along this track and the velocity profile that the pantograph have to do.

The velocity profile can be insert by defining different velocity level along the simulation time. The data is then interpolated with a linear function and can be see on the three graph on the rigth by pressing the plot button.

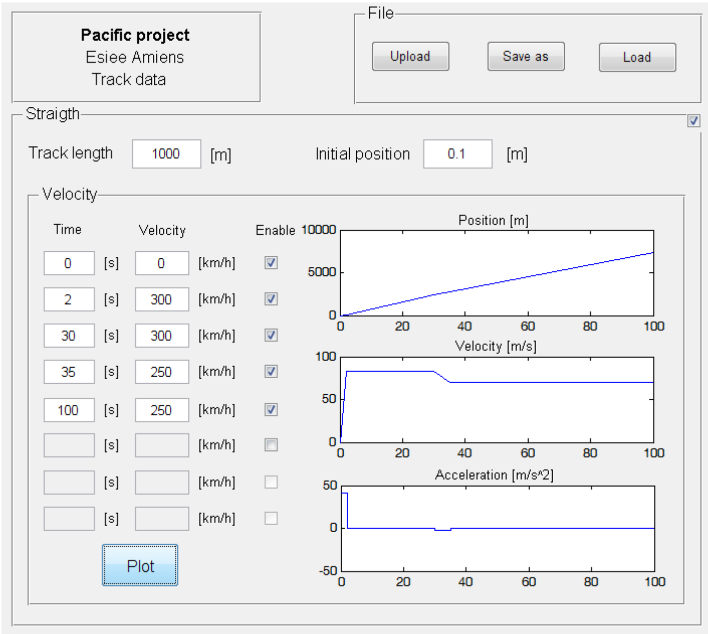


Figure 5: Track panel window

1.4.Fault panel

This panel is yet to be implemented due to the fact that the Euler Bernoulli Timoshenko model have still to be implemented inside this GUI window.

1.5. Force/Control panel

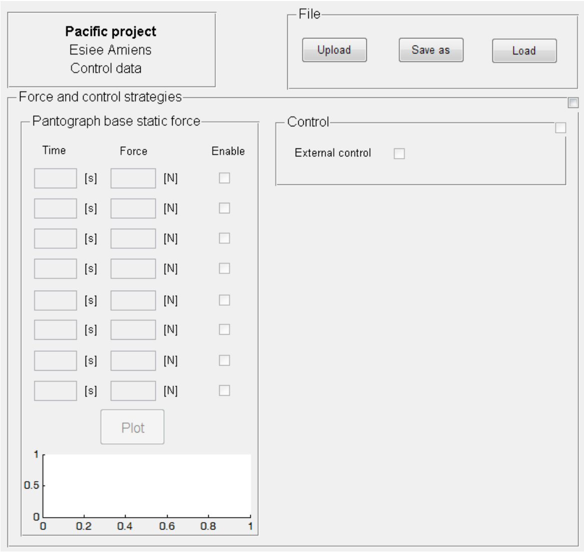


Figure 6: Force/Control panel window

Even inside this panel can be found the File box with the option necessary in order to upload, save and load the desired data.

After having enabled the force and control strategies box it is possible decide the static force that is applied to the pantograph base in order to guarantee the contact between pantograph and catenary. This can be done, like for the velocity profile, by inserting the desired value of force applied to the lower mass at each time. After this the overall profile is then obtained by means of linear interpolation and can be show by pressing the plot button.

On the rigth part of the window it is possible to enable, or disable, the external control strategy develop by the operator and applied to the head or the base of the pantograph structure.

2. Simulation:

When a minimum set of data are correctly insert the Simulation State will become “Ready” and the START button will become enable.

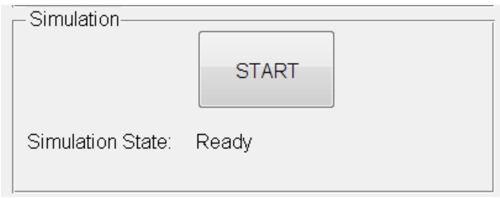


Figure 7: Simulation Box on the Front Panel window

START button will open a new Matlab window that, automatically, will launch the Simulink GUI_model.mdl file.

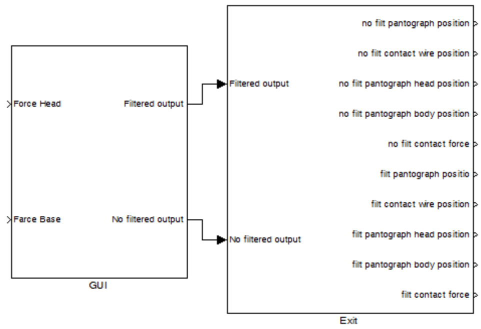


Figure 8: GUI_model.mdl blocks

The GUI subsystem is an S-function with the overall pantograph/catenary model that accept, when external control is enabled inside the force/control panel, external force applied on the head and/or body part of the pantograph that are going to be added to the static ones defined inside the force/control panel and as an output give the position of the pantograph along the track, and the vertical position of each element of the system: contact wire, pantograph head, pantograph body with and without a 20Hz lowpass filtering stage.

At the end of each simulation, in order to continue with the GUI interface it is necessary to close the new Matlab window and so the program will allow to make a first result analysis.

All the output of the simulation can also be retrived inside an external file named output.mat that can be found at the end of each simulation in the same folder of all the other files. This files give all the output in the following order:

- Simulation time;
- Pantograph position along the track;
- Catenary vertical position over the contact point;
- Pnatograph head position;
- Pantograph body position;
- Contact force.

All this data are provided without any filtering operation and can be used for further off-line experiment.

3. Post processor:

After a simulation is done a first visual and statistic analysis can be performed by pushing the “Result Analysis” button.

Inisde this window it is possible to select both the contact force or catenary displacement over the pantograph contact slide and a first set of statisctic data calculated along the last 5 second of simulation results.

As a future improvement, as soon as the Euler Bernoulli Timoshenko model will be implemented, the overall catenary displacement along time will be displayed using the time bar already placed inside the windows.