A Three-Dimensional Dynamic Simulator for the Pantograph-Catenary System

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Numerical simulation programs to calculate the dynamic behavior of the pantograph-catenary system are an extremely useful tool to design and develop pantographs and equipment/facilities of the overhead contact lines. Japan has a long history of simulation technologies in this regard. Fujii and Ebara at Tokyo University developed the first simulation program in the late 1960s to analyze the motion of the pantograph-catenary system based on the finite difference method. By means of continuous upgrade, this program is still used widely even now in Japan.

However, as the program doesn't consider the geometrical non-linearity of catenary suspension components, it doesn't correctly express the three-dimensional motion of droppers or registration arms. It also does not exactly reproduce the phenomenon of trolley wires being pulled up by the lateral tensile force at the supporting points. Thus, the Railway Technical Research Institute (RTRI) developed a new three-dimensional dynamic simulator for the pantograph-catenary system (GASENDO-FE) by applying the non-linear finite element method.

This simulator models contact wires, messenger wires and other principal wires that are little affected by the motion-induced geometrical non-linearity as linear Euler beam elements (Fig. 1). Conversely, registration arms and catenary suspension components such as droppers and hangers are modeled as bar elements to take into consideration the tangential stiffness and to reflect their geometrical non-linearity. As droppers and hangers are structured to slacken in case the uplift of the contact wire is large, this simulation program switches the natural length of dropper and hanger model according to the uplift of the contact wire.

In the actual calculation, the program first determines the static structure of the overhead contact lines based on the input data, such as the dimensions of wires and catenary suspension components and boundary conditions of messenger wire supporting points, wire termination points at the ends and registration arms fixing points. After that, the program calculates the dynamic behavior by performing step-by-step integration of the equations of motion. At each time step in the step-by-step integration, the program repeats the iterative calculations until the non-equilibrated force at each node takes the allowable small value by the Newton Raphson method. The program applies the Penalty method to calculate the contact force between contact wire and pantograph.

Figure 2 shows an example of the calculated static structure of the compound catenary system for Shinkansen. In this figure, the contact and auxiliary messenger wires are pulled up by the lateral tensile force at supporting points, as the contact wire is set with a stagger of ±200mm. Figure 3 illustrates the calculated dynamic behavior of the system when two pantographs ran beneath the overhead contact lines at 300km/h on the assumption that a lateral wind at 25m/s is blowing. The calculation indicates that the contact force fluctuates to a large extent in the vicinity of the supporting points with registration arms positioned on the windward side.

The program uses a mass-spring model to analyze the motion of the pantograph. But, it is now possible to use a multi-body model of the pantograph to analyze the motion of a pantograph alone (Fig. 4). Therefore, RTRI will combine this multi-body model with the simulator introduced above to realize simulation at higher precision in the future.

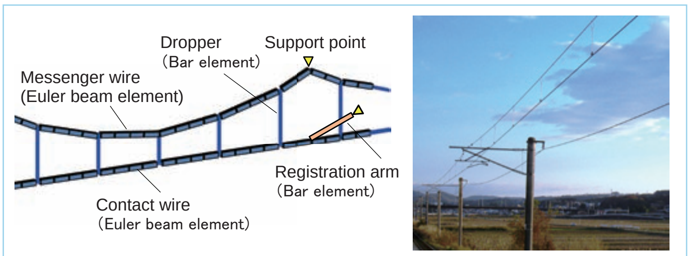

Fig. 1 FEM model of catanary system

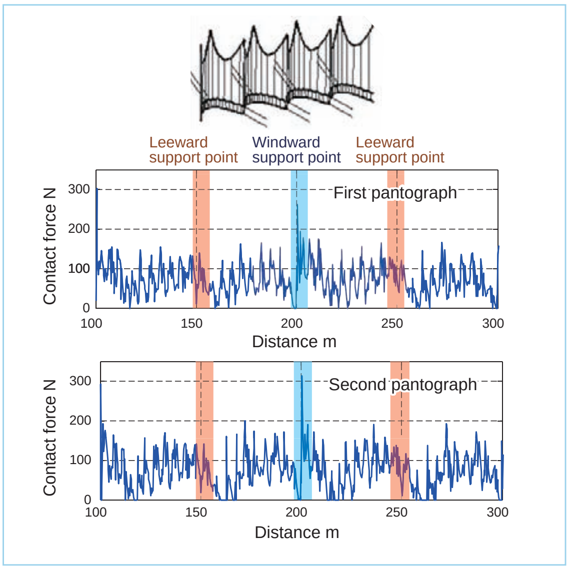

Fig. 3 Calculation result of dynamic interaction between pantograph and catenary

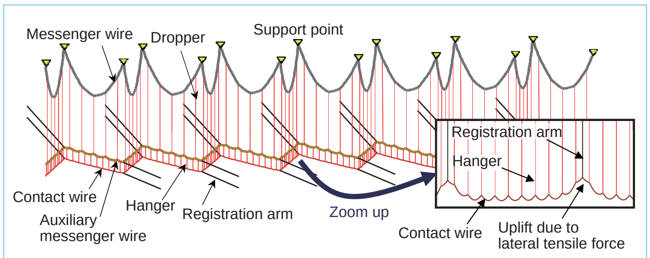

Fig. 2 Calculated static structure of compound catenary system

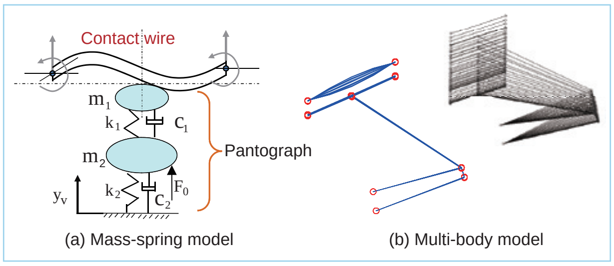

Fig. 4 Pantograph model