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Developing an Inerter Model using Multibody Dynamics Software

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Inerter, railway vehicle suspension, dynamic system modelling, multi-body dynamics

1. Introduction

The inerter is a passive, mechanical device, which produces a force proportional to the relative acceleration between its ends. Theoretically, the inerter forms a complete set with the spring and damper to realise general passive mechanical impedances. If correctly used in a vehicle suspension, this can result in improved control of vehicle behaviour.

The inerter is in commercial use in motorsport, but so far, there have only been theoretical studies, based on simplified vehicle models, of possible benefits for dynamic systems such as railway vehicles [1-3]. The lack of an inerter model in commercial multi-body dynamics software is one of the barriers to further exploring the benefits of inerters. This abstract proposes a method for modelling inerters using a commercial software package (Vampire®). The dynamic behaviour of the inerter model is then compared to theoretical calculations and previously validated Matlab models.

2. Inerter Model

One realisation of the inerter uses a rack and pinion design with a flywheel as shown in Figure 1 [4].

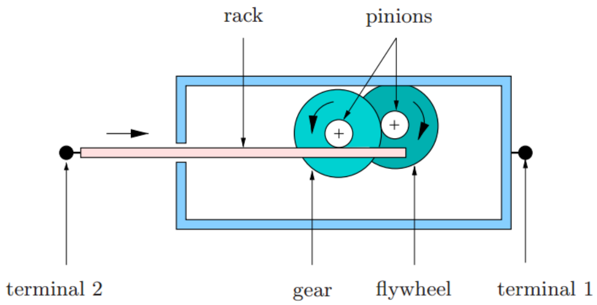

Figure 1 Rack and Pinion realisation of the inerter

The dynamic equation for this system is (assuming the mass of gears, housing etc. is negligible) [4] :

$$F = m\alpha_1^2\alpha_2^2(\dot{v_1} - \dot{v_2}) = I\frac{R_2^2}{R_1^2R_3^2}(\dot{v_1} - \dot{v_2}) \qquad \text{Equation 1}$$

where $\alpha_1 = \sqrt{I/m}/R_3$, $\alpha_2 = R_2/R_1$, I is the inertia of the flywheel, R_1 is the radius of the rack pinion, R_2 is the radius of the gear wheel, R_3 is the radius of the flywheel pinion. The transmission ratio i from the rack to the flywheel is $\frac{R_2}{R_1\,R_3}$ rad/m. Thus the inerter coefficient $b = F/(\dot{v_1} - \dot{v_2}) = Ii^2$.

The rack and pinion realisation of the inerter suggests the approach to modelling shown in Figure 2. This figure shows a three-mass system, where Mass1 and Mass2 may only move vertically and are connected to the two terminals of the inerter. Mass3 may only rotate and plays the role of the flywheel in the inerter. The rack and pinion mechanism is modelled using the 'Link Format', which is a special function in Vampire. The Link Format can connect the movements of two or more masses. To model the inerter, the vertical movement of Mass1 and Mass2 and the rotational movement of Mass3 are linked with a ratio of i_{link}. This link is defined so that one unit of vertical displacement of Mass1 will result in an i_{link} unit of rotation for Mass3 and a unit of vertical movement in the negative direction for Mass2.

Then the inerter coefficient b is calculated using the following equation.

$$b = \frac{I_y}{i_{link}^2} \qquad \text{Equation 2}$$

I_y is the pitch inertia of Mass3. Equation 2 is consistent with the formula given in Equation 1.

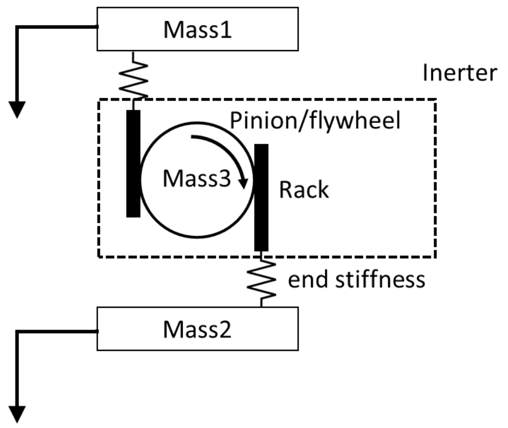

Figure 2 Detailed model of an inerter in Vampire

3. Validation Results

Four suspension layouts that could be used to improve the dynamic performance for railway vehicles are proposed in [2]; railway vehicle models have been created in Vampire that replicated these previous models [2]. Figure 3 shows the comparison of the responses of the vehicle body's lateral displacement of the Vampire model (with or without inerters) and the Matlab model from [2] as the benchmark. The comparisons prove that the Vampire model with an inerter has identical performance to that of the benchmark. The effect of the inerters is also seen to be very significant.

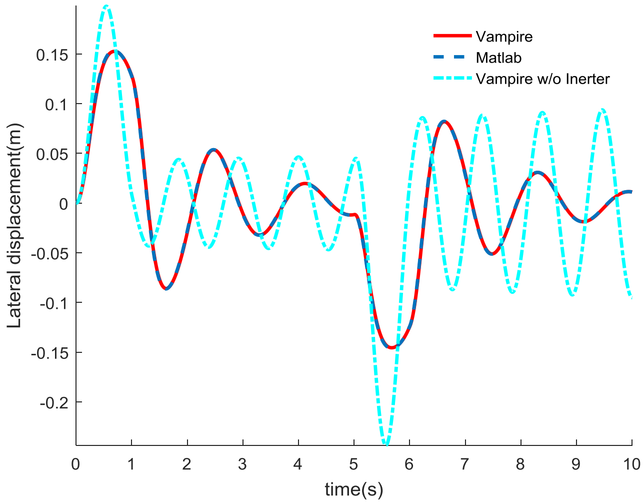

Figure 3 Vehicle lateral displacement response from different models

Future studies will use the validated inerter model to evaluate the benefits of using inerters in railway vehicles. For example, the vehicle's curving performance can be potentially improved without reducing stability by integrating inerters into its primary suspension.

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