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Low order continuum-based liquid sloshing formulation for vehicle system dynamics

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Abstract— The objective of this investigation is to develop a low order continuum-based liquid sloshing model that can be successfully integrated with multibody system (MBS) algorithms. The liquid sloshing model proposed in this investigation allows for capturing the effect of the distributed inertia and viscosity of the fluid. The fluid viscous forces are defined using the Navier-Stokes equations. In order to demonstrate the use of the approach presented in this study, the assumption of an incompressible Newtonian fluid is considered with a total Lagrangian approach. Fluid properties such as the incompressibility condition are formulated using a penalty method. The low order model that captures the effect of the distributed fluid inertia on the vehicle dynamics is developed in this investigation using the floating frame reference (FFR) formulation. The use of this approach allows for developing an inertia-variant fluid model that accounts for the dynamic coupling between different modes of the fluid displacements. The matrix of position vector gradients and its derivative are formulated using the FFR kinematic description. The position and velocity gradient tensors are used to define the Navier-Stokes stress forces. The proposed liquid sloshing model is integrated with a MBS railroad vehicle model in which the rail/wheel interaction is formulated using a 3D elastic contact formulation that allows for the wheel/rail separation. Several simulation scenarios are used to examine the effect of the distributed liquid inertia on the motion of the railroad vehicle.

The results, obtained using the sloshing model, are compared with the results obtained using a rigid body vehicle model. The comparative numerical study presented in this investigation shows that the effect of the sloshing tends to increase the possibility of wheel/rail separation as the forward velocity increases, thereby increasing the possibility of derailments at these relatively high speeds.

Index Terms— liquid sloshing, floating frame of reference, total Lagrangian finite element formulation, rail road vehicle systems, multibody system dynamics

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