Application of multidomain physical systems modeling techniques for assessment of vehicle stability of tipper trailer during unloading

MICHAŁ KONTNY
PIOTR KOWALSKI *

* Mgr inż. Michał Kontny, michal.kontny@polsl.pl – Wydział Mechaniczny Technologiczny Politechniki Śląskiej, Gliwice, Polska
Mgr inż. Piotr Kowalski, pk1977@o2.pl

This paper presents the case of application of multidomain physical systems modelling techniques in the area of heavy transport vehicles. The presented techniques allow for faster developing of complex physical systems models. The paper presents portions of the model built for simulating the stability of trailer dumper during tipping.

KEYWORDS: multidomain physical systems modeling, CAE, vehicle stability

Introduction

Tipper trailers belong to the basic means of transporting loose materials. They are used, among others for the transport of agricultural products, coal and building materials. This type of trailer is unloaded by lifting the load box using a hydraulic cylinder. Unloading the dump truck requires observing the necessary safety measures: the vehicle must be placed on level and stable ground, the air suspension bellows should be vented, the tractor unit should be positioned in the trailer axle. It is also important to provide adequate tire pressure. Non-observance of precautionary measures may lead to buckling and, consequently, breakage of the hydraulic cylinder, loss of stability of the vehicle combination and overturning.

The purpose of this paper is to present the possibility of applying methods of simulations of multi-domain physical systems to test the stability of tipper trailers.

Trailer construction

Tipper trailers used on the European market are generally built of a steel frame based on two longitudinal beams. The load box is articulated to the rear of the frame. The body is lifted by means of a multi-stage hydraulic cylinder connecting the front part of the frame to the load box.

There are two main types of suspension for tippers: pneumatic and mechanical. The most common application is vehicles with air suspension – this solution is also preferred because of the lower load on the road infrastructure.

Unloading is carried out using a hydraulic system.

Object model

A precise representation of vehicle behaviour requires consideration of:
- interaction of the trailer and tractor unit,
- the load’s impact on the trailer,
- mutual interaction of trailers’ subsystems.
One of the possibilities of mapping the work of systems is representation in the form of differential equations.

The work [1] presents a pneumatic suspension model used to study the impact of load changes on the operation of the trailer suspension system. Equations describing behavior of the object were derived from the geometrical form of the system and physical dependencies.

For complex systems, developing a model using equations is time-intensive.

One of the tools simplifying the process of modeling and simulation of systems is the Simscape program [2], available as a Matlab software module.

Simscape provides a set of blocks representing the components of real physical systems. Individual blocks are connected to each other by means of lines representing the flow of a physical signal. The software also enables the import of external object geometry.

Fig. 1. Block diagram of the trailer model developed in the Simscape software – high level presentation
Object geometry

For the purposes of the research, it was decided to use a simplified representation of the geometric form of the trailer (fig. 2). The main components – such as a load box, frame, cylinder and a single rigid axle – have been modeled in external CAD software. Geometry developed in this way was imported into Simscape.

To define the motion connections, the options available in the Simscape program were used (the program offers a wide range of joints with different degrees of freedom, from the simplest cylindrical joints to gimbal joints, and also allows to specify the parameters specific to a particular joint, e.g. stiffness or damping).

Pneumatic system

The compressed air is used in the trailer as a working medium in braking and suspension systems. Compressed air is generated in the truck and transmitted to the trailer by pneumatic lines. The prepared model includes only the part related to the pneumatic suspension system. A pneumatic spring model with non-linear characteristics was developed (i.e. a change in its effective surface depending on the extension was taken into account).

In real trailers, the working height of the trailer is adjusted during travel by means of a ride height valve (fig. 3). This makes it possible to maintain the required position under different loading of the trailer, regardless of the actual load being transported. In the case of the discussed model, a mechanism was used to regulate the air supply to the bellows depending on the temporary position of the suspension.
Hydraulic system

Like in the case of air supply, the hydraulic system is powered from the tractor unit. The model implements a system responsible for controlling the operation of a hydraulic pump. Oil under pressure is fed to a three-stage hydraulic cylinder. Figure 4 shows a fragment of the hydraulic system that lifts the load box.

Blocks available in the Simscape software belong to the so-called domains. Mechanical, hydraulic and pneumatic domains were used to build the model. To develop the actuator model, "Translational Hydro-Mechanical Converter" blocks (I, II and III stage of the actuator in fig. 4) were used, combining the mechanical domain (green lines) and hydraulic one (yellow). The ability to control the hydraulic system has been introduced.

Payload representation

The center of gravity of the load has a key impact on the stability of the trailer. In the discussed model, the load impact on the trailer was implemented using the "Variable Mass" element, available in the Simscape software. It is possible to model changes in mass value and the location of the load center of gravity as unloading progresses. The physical properties of the load are described by such parameters as: initial volume, density and angle of repose [4]. In addition, it is possible to simulate the hopping of the load (e.g. when unloading wet materials or when sticking in the load box occurs).

Excitation

A mechanism has been developed to map the unevenness of the terrain, on which the trailer moves. Three independently controlled platforms were used to lift: the left wheel, the right wheel and fifth-wheel. The software used allows for the control of the excitations.

Simulation

A simulation of the trailer’s behaviour during unloading in the event of insufficient pressure in the right wheel was carried out. A simplified model in the form of a spring with specified stiffness was used to represent the tire [5]. The tire stiffness coefficient depends on the inside air pressure [6], so a reduced rigidity coefficient was assumed for a wheel with a lower pressure.

The trailer was aligned with the tractor unit representation, the suspension was vented. Figure 5 shows the course of kinematic excitations corresponding to driving on uneven ground. Moving the vehicle during unloading is not recommended, nevertheless it is a common practice.

Figure 6 shows the instantaneous mass of the load as a function of time. Lifting the box begins in the 40th second of the simulation, but the load begins to slide later – according to the accepted scenario. This corresponds to a load dropping in portions.
Fig. 5. Time course of kinematic excitations

Fig. 6. Instantaneous mass of load remaining on the tipper

Fig. 7. Tipping body tilt chart
Figure 7 presents the tipping angle of the dump truck (measured in the global coordinate system) during unloading for two cases: for the correct pressure in both tires and for reduced pressure on one side of the trailer. As it can be seen, with incorrect pressure in the wheels, there is a greater lateral tilt of the trailer (rotation relative to the longitudinal axis), which reduces the stability of the vehicle.

Summary

The use of multi-domain object modeling tools accelerates building of models of complex physical systems. The presented method includes importing the external geometry, mapping connections between elements and connecting the subsystems (mechanical, pneumatic, hydraulic, control, etc.).

When adding new elements to complex models, it is recommended to check the correct operation of the model. It is important to choose the right parameters such as stiffness and damping of the joint. Too much stiffness in the model can lead to numerical errors or a significant extension of the simulation time.

In the considered case, the usefulness of the developed model for simulation of the impact of incorrect wheel pressure on tipper stability was confirmed. The model contains all main systems of the trailer, which allows the simulation of operation and possible malfunctions of the hydraulic or pneumatic system. Due to the computational complexity, the model has been presented in a simplified form – for the purposes of more detailed analysis, this model should be further developed, including by more accurate geometry mapping or adding additional axles. Geometry of the mechanical system is represented by rigid bodies, thus phenomena related to deformations of the trailer elements are omitted.

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