Multi-Body Dynamic Analysis of Lifting and Steering Mechanisms

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Abbreviations: MBD-Multi-Body Dynamics, CG-center of Gravity.

Keywords: Multi-Body Dynamics, Joint Forces, Mechanisms, Kinematics

Abstract

Kinematic and dynamic analysis of simple mechanisms involving sliding, revolute and spherical joints is conducted using MotionView and MotionSolve modules of Altair HyperWorks. The applications under consideration are the motion and force analysis of lifting boom, hood opening and steering mechanisms of heavy off-road vehicles. The quasi-static forces computed at the joints using multi-body dynamic analysis is compared with the analytical calculations and the finite element analysis. The output of the analysis is used to check the basic feasibility of the mechanisms. The force information at the sliding joints is used for the optimum selection of the hydraulic cylinders.

Introduction

A mechanism consists of a number of rigid bodies or links connected to each other in such a way that the desired output for a given input can be derived. Different kinds of mechanisms are used in most of the engineering equipments. Analysis and synthesis of mechanism is a key activity during design and development process of any mechanical system. Multibody dynamics is the analysis of dynamic behavior of interconnected rigid or flexible bodies when they undergo translational and rotational displacements. The study of MBD is important to understand how a mechanism behaves under the influence of forces and what forces are necessary to make the mechanical system move in a specific manner. Hence MBD simulations tool can help to predict kinematic and dynamic behavior early in the stage of design cycle.

In the current study kinematic and dynamic analysis of simple mechanisms involving sliding, revolute and spherical joints is conducted using MotionView and MotionSolve modules of Altair HyperWorks. The mechanisms under consideration are mainly for lifting and steering applications. The main objective is to check the mechanism feasibility and to extract the dynamic joint forces. The extracted force information is further used for optimum selection of the components such as hydraulic cylinders, gas springs etc.MBD model of mechanism is created in MotionView with appropriate mass inertia properties and relevant joints between rigid bodies. The feasible motion is defined and model is solved in MotionSolve. The output results are post-processed using HyperView and HyperGraph and compared with analytical calculations.

Mechanisms

Mechanisms used in this study are Steering mechanism, Boom lifting mechanism and Lid mechanism.

Steering Mechanism

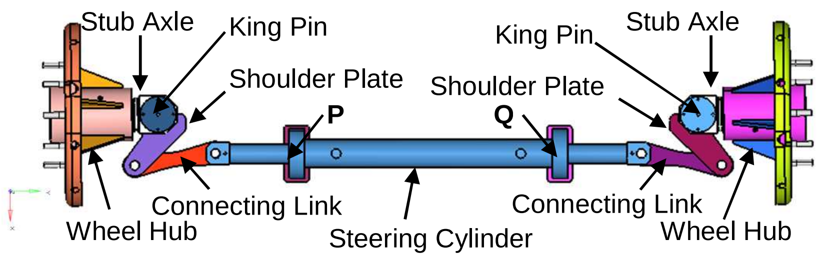

Figure 1: Steering Mechanism

Steering mechanism is shown in Fig.1. The main components are steering cylinder, stub axle, wheel hub and connecting links. Steering cylinder is fixed on steering axle at point P and Q and tyre will be placed on wheel hub. When hydraulic pressure is applied inside double acting steering cylinder, the piston will move and push connecting link. Due to this stub axle will rotate about king pin axis (Z axis) as shown in figure.

Boom Lifting Mechanism

Fig.2 shows boom lifting mechanism. Outer boom, inner boom lift cylinders and extension cylinder are the main components. This mechanism is connected to vehicle frame at point 1 and point 2. Inner boom and outer boom are connected together with extension cylinder at inside. When hydraulic pressure is applied inside lift cylinder, the outer boom along with inner boom and extension cylinder are lifted up around pivot point 2.

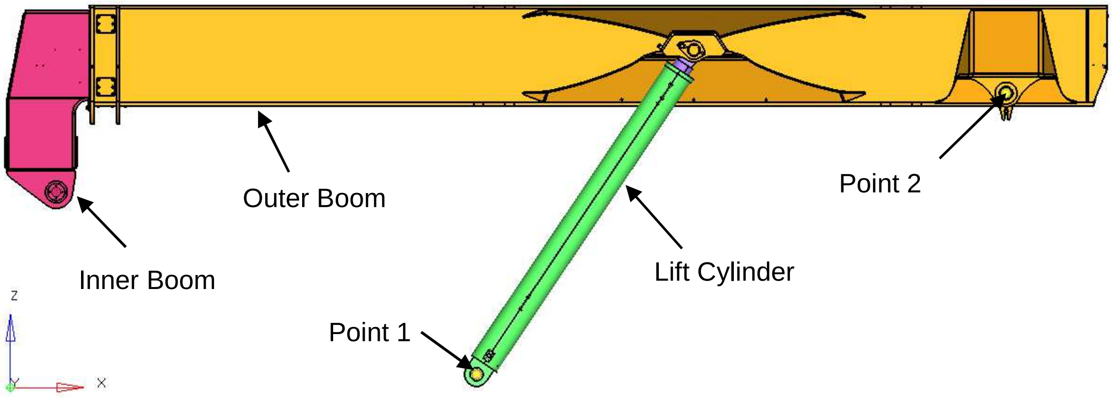

Figure 2: Boom Lifting Mechanism

Lid Mechanism

Lid mechanism is shown in Fig.3. Lid and gas spring are the components of this mechanism. Once we pull the lid, due to gas force inside gas spring, the lid gets lifted up around point D and reaches its extreme position. Similar kind of mechanism can be found in the trunk lid of a car and engine hood of off-road vehicles.

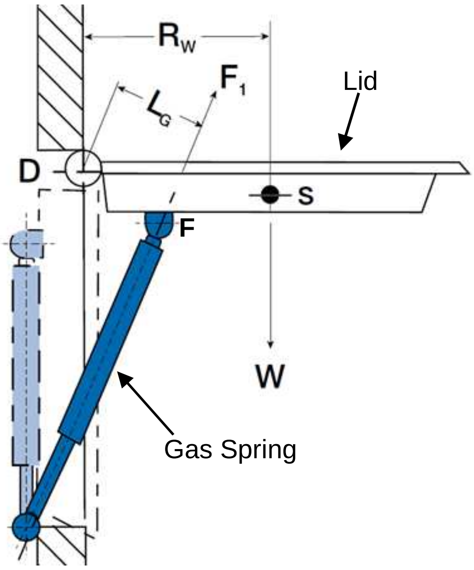

Figure 3: Lid Mechanism [4]

MBD Models in Motion View

Defining correct mass inertia properties and CG location will ensure accurate output response in MBD analysis. This can be done by importing CAD model in MotionView and assigning density which will automatically calculate its CG location and mass inertia or we can create body at appropriate CG location and assign relevant mass inertia properties. The mobility of the mechanisms is calculated using Kutzbach criterion for spatial linkages. Detailed MBD model of steering, boom lifting and lid mechanism are discussed below.

Steering Mechanism

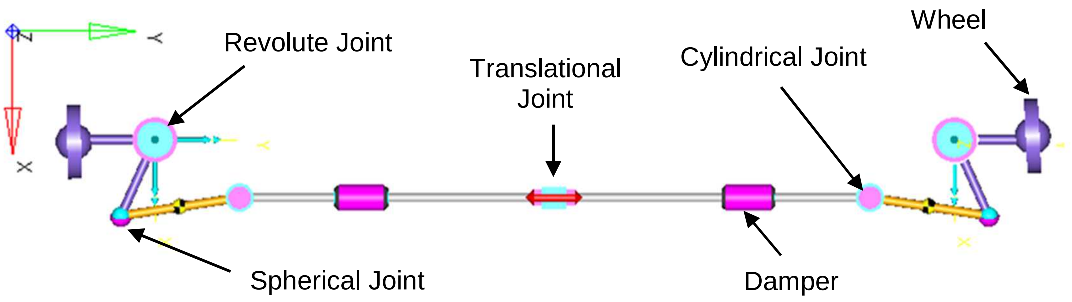

Figure 4: MBD Model Steering Mechanism

The MBD model is simplified into links of steering mechanism as shown in Fig. 4. The kinematic analysis is carried out by applying a constant velocity V at the steering cylinder with respect to the axle frame/ground. The value of V is chosen based on the functional requirement of mechanism. The steering cylinder is modeled as a translational contact. The joints between the connecting links and the steering cylinder are modeled as cylindrical joints. The wheel, stub axle and shoulder plate are modeled as a single rigid body pivoted about the kingpin using a revolute joint. The joint between the stub axle-wheel assembly and the connecting link is modeled as a spherical joint. Kinematic analysis is used to check motion feasibility.

The dynamic analysis is performed by applying a longitudinal force F along y axis on steering cylinder. Road resistance is applied as an opposing torque at the kingpin. The resistive torque at the wheels is analytically calculated based on the mechanism design, tyre dimensions, load on the wheel and the friction between the tyre and the ground. The minimum force required to overcome the road resistance and give the desired motion is checked through dynamic analysis. This is used to select the hydraulic cylinder capacity. Dampers are added solely to calculate the lateral force on the cylinder.

Boom Lifting Mechanism

MBD representation of boom lifting mechanism is shown in Fig.5. Joints are created at respective locations as shown in figure.

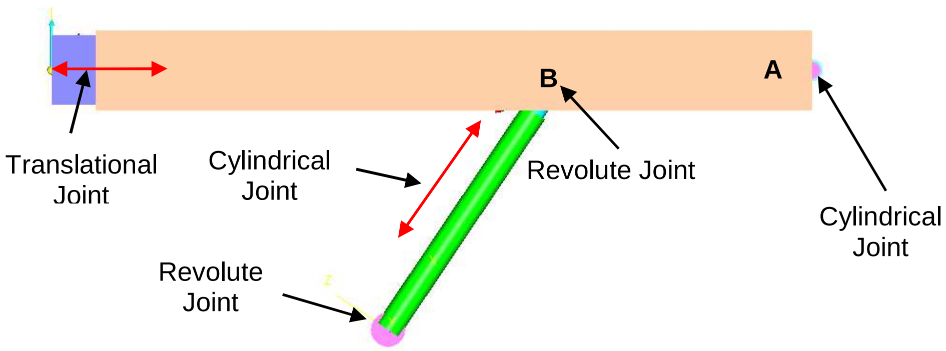

Figure 5: MBD Model Boom Lifting Mechanism

The load is applied at one end of the inner boom as per the study project requirement. The analysis is carried out by defining a constant velocity input at the lifting cylinder joint. The output forces are extracted at point A and point B. The joint forces serve as useful input load for the component level finite element analysis.

Lid Mechanism

The MBD model of lid mechanism is shown in Fig.6.

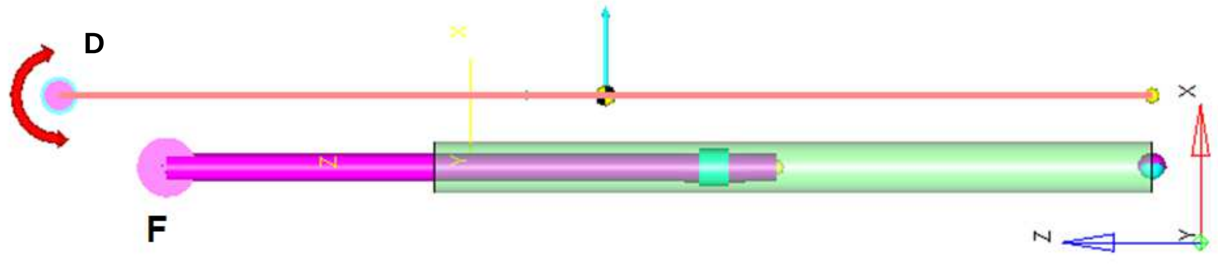

Figure 6: MBD Model Lid Mechanism

The joint inside gas spring is modeled as cylindrical joint. The revolute joint is created between gas spring and lid at point F. The lid pivoted at point D is modeled as revolute joint. The gas spring is connected to ground with a spherical joint. The input motion is defined at pivot location point D. The load W is the self-weight of lid and the gravity is defined in Z direction. The output forces are extracted at point F.

Results and Discussion

MBD models are solved in MotionSolve. Output results for the different mechanisms are discussed below.

Steering Mechanism

Ackerman angles obtained from kinematic analysis of the steering mechanism are shown in Fig. 7. The plot shows the rotation of the inner and the outer wheels about the king pin center with respect to the non-dimensional stroke length of the piston. The simulation results match with the analytically calculated wheel turning angles. The analysis confirms motion feasibility of steering mechanism.

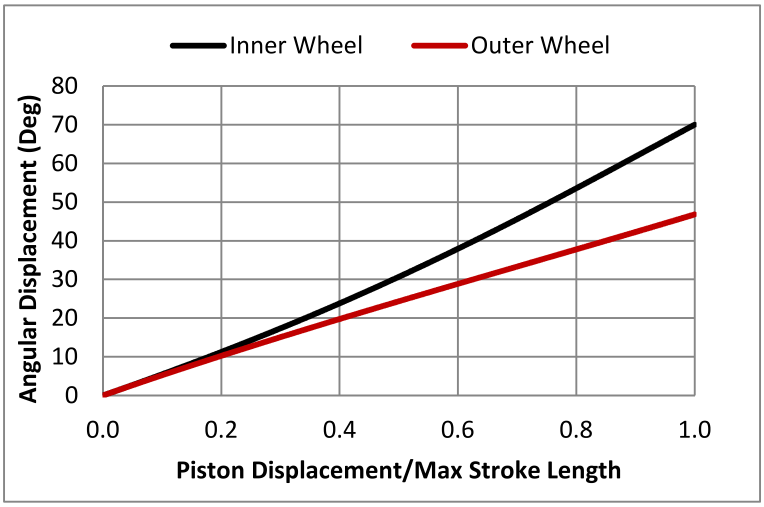

Figure 7: Ackerman Angles

The dynamic analysis shows that the applied force is sufficient to overcome the road resistance. The analysis provides additional force information at different joint locations. The ratio of lateral force to the applied longitudinal force on the steering cylinder is measured at the bush locations as shown in Fig. 8. The observed high lateral force may lead to leakage problems in the hydraulic cylinder over a period of time.

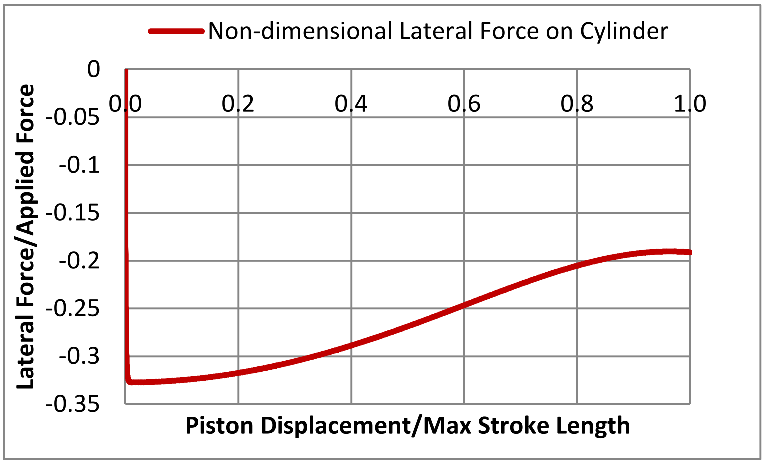

Figure 8: Ratio of Lateral Force to Applied Force on Steering Cylinder

Boom Lifting Mechanism

The non-dimensional reaction forces for boom lifting mechanism measured at joints A and B along the vertical direction are shown in Fig.9.

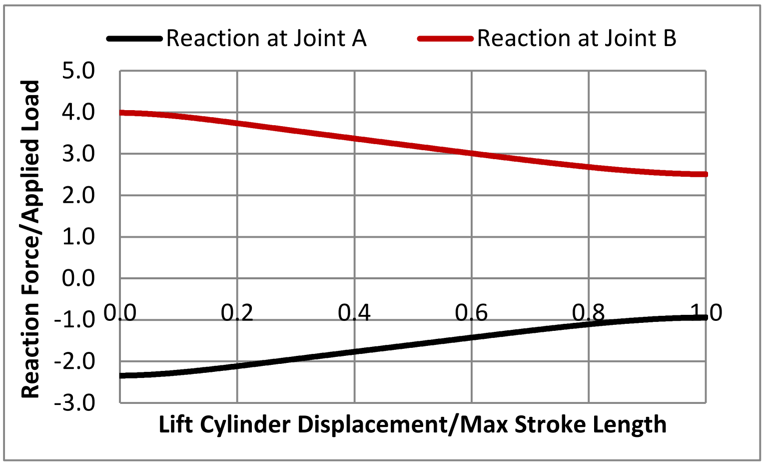

Figure 9: Ratio of Reaction Force to Applied Load on Joints A and B

The plot shows the reaction forces with respect to cylinder stroke length. Table 1 shows the comparison of joint forces obtained by MBD, FEA and analytical methods for the initial position of the mechanism.

Table 1 : Comparison of MBD forces

Location	Reaction Force/Applied Load		
	MBD	FEA	Analytical
A	-2.34	-2.28	-2.29
B	3.99	3.90	3.90

Lid Mechanism

The non-dimensional reaction force at joint F between the gas spring and the lid is shown in Fig.10.

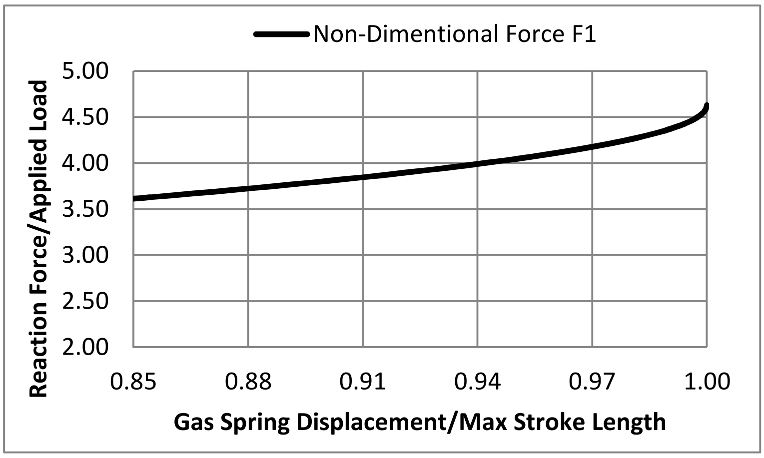

Figure 10: Ratio of Reaction Force to Applied Load on Joint F

The force at F predicted by MBD is 4.63 and it matches with the analytically obtained value of 4.62. This force data is useful for selection of gas spring in the design process.

Benefits Summary

- The output response is useful for component selection, thus reducing the overall design cycle time
- The mechanism feasibility can be easily verified.
- MBD analysis provides information on possible causes of problems in mechanism, like leakage in hydraulic cylinder.
- The force output of MBD analysis is useful as an input to FEA analysis.

Future Plans

To evaluate critical position and stresses of mechanical system for any loading during its operating cycle using flexible MBD simulation of Altair MotionView/MotionSolve. The contact between the ground and the tyre in steering mechanism also needs to be studied.

Conclusion

In the current study multi-body dynamics analysis is performed for steering and lifting mechanisms.

- Altair MotionView/MotionSolve is effectively used to perform kinematic and dynamic analysis of load lifting, hood-opening and steering mechanisms in off-road vehicles.
- The mechanism feasibility is verified by kinematic analysis.
- The output force of MBD analysis closely matches with analytical/FEA forces.

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