DYNAMIC ANALYSIS OF MULTI-BODY VEHICLE FITTED WITH CONTROLLED LIMITED-SLIP DIFFERENTIAL USING MSC.ADAMS/CAR

Mohit Goel*, Nalinaksh S.Vyas**

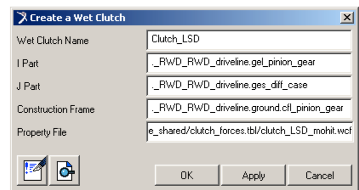
**Scientist, Instruments Research and Development Establishment, Dehradun, India*

***Professor, Indian Institute of Technology, Kanpur, India*

SUMMARY: In the present article, a multi-body vehicle with controlled LSD, built using ADAMS/Car, is described. Mechanical layout of LSD is specifically constructed. The multi-body vehicle model is further validated through its simplified analytical model having few degrees of freedom and tyre sub-system only. Simulation results for a particular maneuver show good agreement between both models except for some quantitative difference.

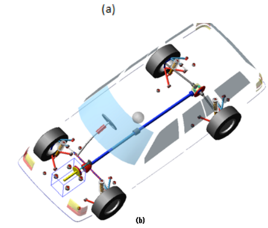
MULTI-BODY VEHICLE MODEL WITH CONTROLLED LSD

In this study, ADAMS/Car® software is used to build the virtual vehicle model. The virtual vehicle model is built by means of sub-systems that are assembled together to obtain the desired model. Assembly of rigid body model of a rear-wheel drive sport utility vehicle is created. Main sub-systems of vehicle are front suspension, rear suspension, steering, front and rear tyres, body (chassis), engine, transmission, rear driveline. Each sub-system, and so the complete virtual model is fully parameterized. In



(a)

ADAMS/Car, mechanical layout of rear drive line with LSD is constructed by incorporating the symmetric conceptual wet clutches in the differential sub-system of the software (Fig. 1(a)). The integrated control system of ADAMS/Car is used to drive the vehicle model during simulation applying the steering input and time variant pressure pattern to the conceptual wet clutches of LSD. In this article, only the results obtained with the integrated control system of ADAMS/Car are presented.

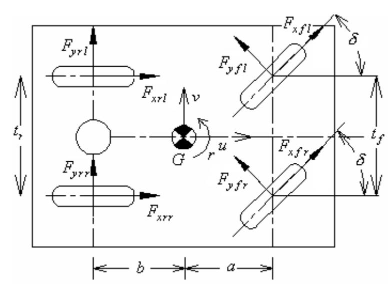


(b)

Fig. 1(a): Modeling LSD in ADAMS/Car.
(b):The complete multi-body vehicle assembly.

ANALYTICAL MODEL OF VEHICLE WITH CONTROLLED LSD

A general four-wheeled rear-wheel drive (rwd) vehicle model [1] is first developed and the model of the rear driveline system containing LSD is added to the vehicle model. The vehicle model takes into account the longitudinal dynamics and load transfer effects. The state variables associated with the model are longitudinal speed (u), lateral speed (v), yaw rate (r) and wheel rotational speeds ($\omega_{fl}, \omega_{fr}, \omega_{rl}, \omega_{rr}$) (Fig. 2 (a)). The non-linear 'magic formula' [2] tyre model is employed in the vehicle model to represent the tyre forces. Controlled LSD (Fig 2 (b)) is modeled by placing the controlled clutch between differential pinion and differential case [3, 4]. The applied normal force p to clutch and corresponding clutch torque T_{CT} regulates the behaviour of LSD to locked ($\Delta\omega = 0$) state or slipping state ($\Delta\omega \neq 0$).The frictional torque T_f generated between clutch plates changes value depending upon LSD states. Depending on whether LSD is slipping or locked, the highly non-linear first order differential equations vehicle model is then numerically simulated for a particular step-steer maneuver using Maple® software.



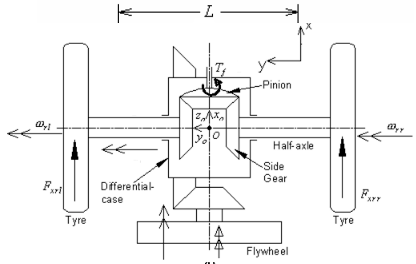


Fig. 2 (a) Parameter and force description of rwd vehicle model.
(b) Mech. layout of rear driveline system with controlled LSD.

SIMULATION RESULTS

Both, analytical and multi-body models of a vehicle with controlled LSD are subjected to the example manoeuver of steering wheel step input (Fig. 3 (a))and a pattern of input clutch torque T_{CT} (Fig. 3 (b) & (c)). The dynamics of vehicle changes with T_{CT} pattern given for obtaining repeated transitions between locked and slipping states of the LSD.

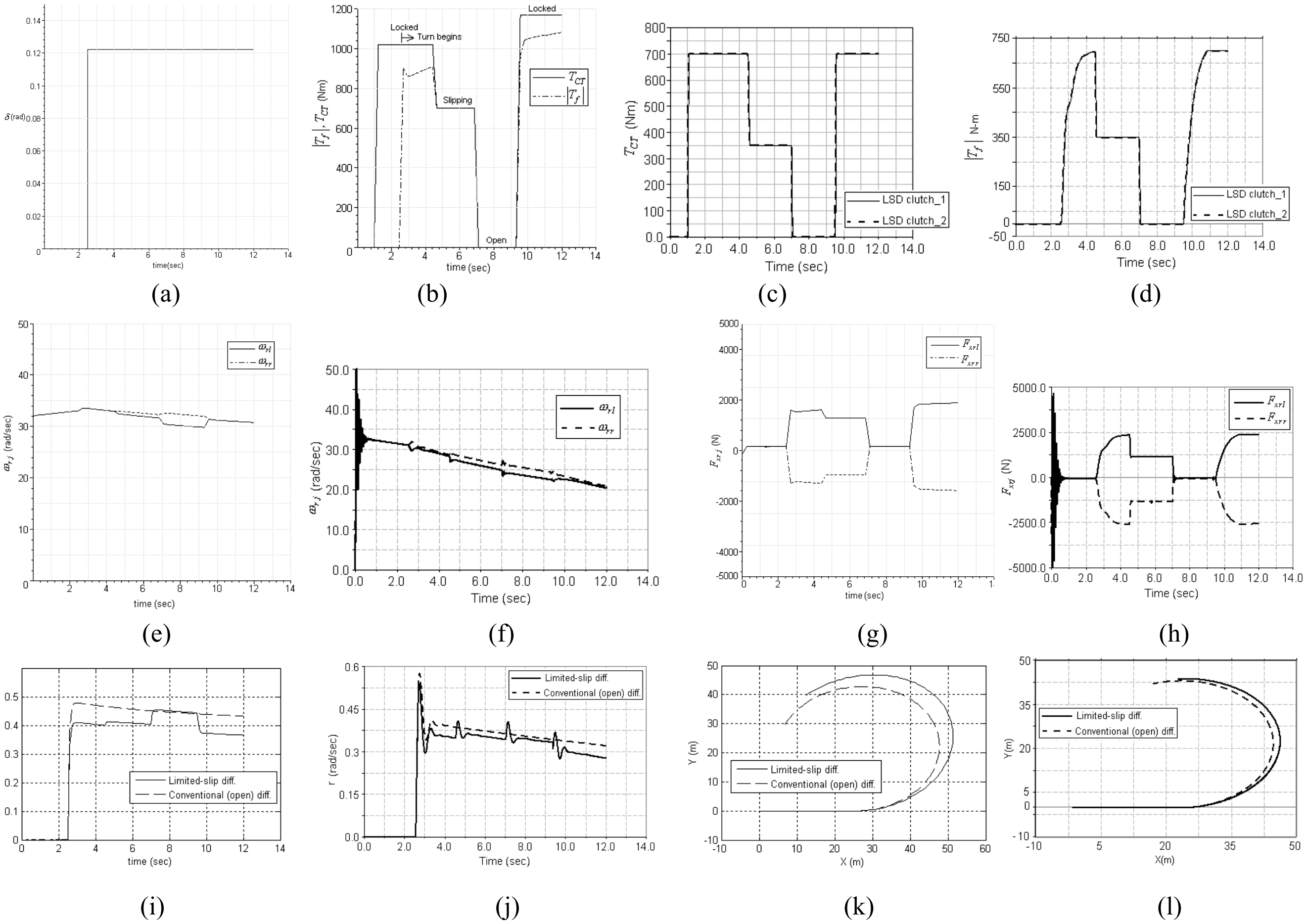


Fig. 3: (a) Steering step input. (b) T_{CT} & friction torque $\left|T_f\right|$ during maneuver with analytical model. (c)&(d) Applied T_{CT} & $\left|T_f\right|$, (e)&(f) Angular velocities ω_{rl} & ω_{rr} of rear driving tyres, (g)&(h) Rear driving tyres longitudinal forces F_{xrl} & F_{xrr}, (i) & (j) Yaw rate r, (k) & (l) Vehicle path, during manoeuver of analytical and multi-body vehicle model.

The simulation results show that both analytical vehicle model and multi-body vehicle model respond in similar manner during maneuver and represent transition states of LSD (i.e. open, slipping & locked). Moreover, the locking/slipping action of the rear LSD also affects the yaw dynamics of the vehicle. It can be seen that some quantitative differences arises. Analytical model includes only the tyre model and does not contain suspension and steering kinematics. Therefore, accurate load transfer effects cannot be determined and correspondingly, tyre forces are not exact as well as applied clutch torque to get the locked LSD. Simulation results also validate the multi-body modeling and simulation of vehicle and LSD using ADAMS/Car.

CONCLUSIONS

A virtual vehicle model with controlled LSD was built using MSC.ADAMS/Car. ADAMS/Car software does not have pre-defined LSD sub-system. Therefore, LSD was created by adding the conceptual wet clutches in differential sub-system of software. The virtual model was validated by comparing the response of its analytical vehicle model having few important d.o.f. Simulation results of virtual and analytical vehicle model show good agreement for a particular step steer maneuver & input LSD clutch pattern. However, there was some quantitative difference because other sub-systems like suspension, & steering used in multi-body vehicle model also have prominent role on dynamics of vehicle. Virtual vehicle model was fully parameterized and could be used to simulate similar types of vehicle. Moreover, analytical vehicle model can form the basis for designing the suitable control strategy required to modulate the behaviour of LSD according to actual driving conditions.

References

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