iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VIII **Month of publication:** August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37604

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Tool Evaluation & Design Analysis for Parking Pawl Mechanism

Amit R. Patil[1], Siddhesh Bandekar[2]
[1, 2]Department of Mechanical Engineering, JSPM'S Jayawantrao Sawant College of Engineering

***Abstract:** Automatic Transmissions in vehicles are becoming the norm today and with the need to reduce fuel consumption, electric vehicles are increasing in number too. As the vehicles get smarter, transmissions have also felt the need to adapt so as to cope with the demands of the 21st century. Apart from providing the user with different driving modes, vehicles with an Automatic Transmission and electric vehicles have a device called a Park Lock. Park Lock Mechanisms are devices that are fitted to vehicles with an automatic transmission or electric vehicles which can secure the vehicle mechanically in addition to the parking brakes to prevent an unintended movement of the vehicle when the vehicle is brought to a stop. This system can face various kinds of loads coming from the transmission or from the wheel side. So, it is necessary to design a system which can withstand against it. Today, when a park lock mechanism is designed, it is designed in a way that it not only fits one vehicle variant but many variants (these variants can include either front wheel drive, rear wheel drive, vehicles with varying final gear to park lock gear ratios etc). Therefore, one Park Lock Mechanism needs to satisfy various conditions and requirements. Carrying out calculations with different notations for each variant becomes a cumbersome procedure, therefore it is prudent to have one common platform which can do the calculation in the early phases of design. In this paper, a closed form calculations-based Excel VBA tool can able to estimate the loads coming on to the Park lock mechanism by doing some background calculation is presented followed by the simulation performed using Multi Body Dynamics software ('ADAMS'). Results from MBD tool and a 1D tool are corelated to the test data to gain some confidence on the tool which created in Excel VBA.*
***Keywords:** Park Lock Mechanism, ADAMS, 1D Tool, Excel VBA, Drop in Speed, Torque Build up.*

I. INTRODUCTION

A Park lock mechanism is a device fitted in an automatic transmission or an electric vehicle to lock up the transmission. It is engaged when the transmission shift lever selector is placed in the "Park" position. By doing this, it will secure the vehicle mechanically to prevent it from unintended rolling. Generally, the park lock system consists of a park gear or park wheel which is on the transmission's output shaft, so the park gear is rotating with the same speed as of transmission output shaft. A park pawl is pivotally mounted within transmission housing with an actuator controller. When the driver moves the lever to the park mode, notch of the pawl engages with one of the teeth on the park wheel. This causes to stops the wheels as no torque is transferred to the wheels. Fig 1. Is an example of typical Park lock mechanism.

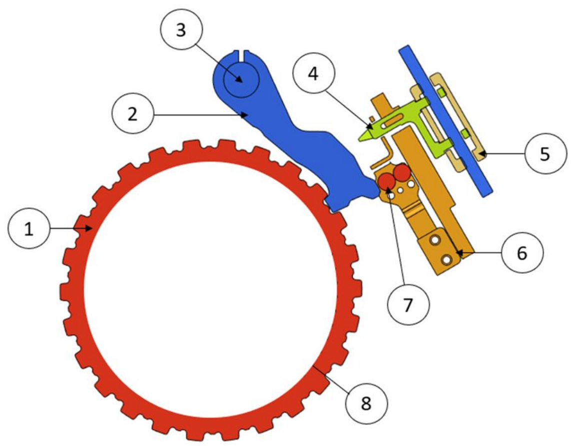

Figure 1 Park Lock Mechanism at engaged position

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Park lock mechanism mostly consist of the part as shown in Fig.1, which includes with,

1) Park Wheel
2) Pawl
3) Pivotally mount location of pawl (Torsional Spring)
4) Fork
5) Cradle Assembly
6) Carriage Assembly
7) Rollers
8) Vehicle Inertia on to the park wheel

II. PARK LOCK DESIGN REQUIREMENTS

All vehicles with an automatic gearbox are required by law to have a mechanism apart from the service brake to prevent the unintentional rollaway of the vehicle after it has been parked. This was enforced by the National Highway Traffic Safety Administration and the standards are called the Federal Motor Vehicle Safe Administration. This can be achieved with the help of Park lock mechanism. The standard pertaining to the park lock mechanism is known as FMVSS 114, which is simply a test procedure which ensures design requirement of Park lock It may seem like a simple thing to lock the transmission and keep it from spinning; but there are actually some complex requirements for this mechanism are like, When the vehicle is traveling at a high speed and park is engaged, the park lock system must ratchet or slip, thereby not engaging until the vehicle has slowed to a targeted "engagement speed". This is generally called the engagement speed test. It is a government requirement that the vehicle cannot engage park above a certain speed. Engaging at a higher speed also causes higher stresses in park lock and other transmission components and can cause wear, fatigue, and eventual failure. When the vehicle is on a hill and the driver has engaged park and lets his foot off the brake, the vehicle must not rollback beyond the targeted "rollback distance". This "rollback test "is also a government requirement. The maximum speed that the vehicle generates when parking on the hill should be lower than the park lock's engagement speed. Otherwise, the vehicle will be rolling down the hill and can't be stopped. The driver has to be able to disengage from park after the vehicle has been parked on a hill, especially after an extended period of time. Once engaged, the park lock needs to stay engaged. The design has to prevent the pawl from popping up and disengaging Fig. 2 is explaining the event of parking pawl engagement.

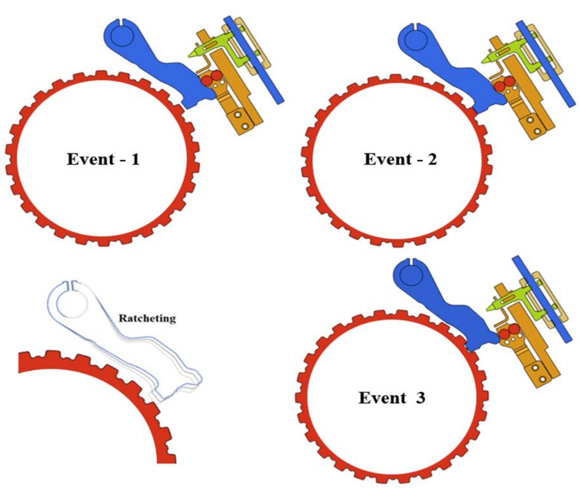

Figure 2 Park Pawl Engagement Events

As mentioned in the requirement once the transmission lever shifts to the park mode, must not become engaged immediately but instead ratchet until the vehicle reaches a speed of less than a targeted value. The velocity at which pawl is engaged with park gear is nothing but engagement velocity or drop in speed. Event-1 in Fig. 2 position of pawl when the transmission lever is not in the park mode. Subsequent Event-2 is the condition where pawl is approaching toward tooth of park gear. Ratcheting event may or may not be happened and the last Event-3 is when the pawl is engaged. From these instances mostly three types of torque, the park lock system may experience i.e., Static torque, Dynamic torque, and the Skid torque From the Excel VBA tool these are the important outputs we can expect.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

III. DERIVATIONS BEHIND THE 1D TOOL

Driver can switch the transmission lever to the park mode in couple of conditions like, Vehicle is parked either on the ramp or at the level ground. Lever can be switched to the park mode either at rest condition or when the vehicle is still running.
Conventional process of gear modelling for finite element analysis purpose consists of various steps. These steps are discussed in below flow chart:

A. Static torque

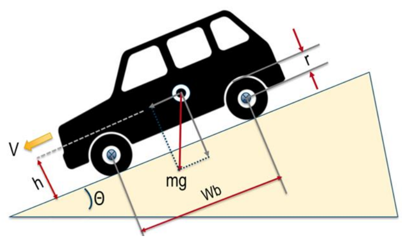

Figure 3 Free body diagram of a vehicle on a slope

The vehicle on the slope and if the park is applied, in this event vehicle gravity components acts long the direction of ramp (mg) and that causes to generate the torque on the wheel. Eventually this torque also experiences in the park wheel nothing but the static torque. In the above equation mg is nothing but the gravitational component, 'r' is the radius of tire, 'Θ'is the slope angle and 'u_2' is the gear ratio from park wheel to output shaft.

B. Dynamic Torque

Dynamic torque is the needed torque to get a full stop of the vehicle when the vehicle is traveling at a certain velocity. This is the condition where the vehicle is moving with certain speed and sudden park is applied to stop the vehicle it creates an amount of torque on the park wheel. In case of electric vehicle, the torque induced in the system is from both the sides i.e. from EDU side and from the wheel. When we apply sudden park; except the park wheel every other part wants to be in motion because of inertia, during this scenario kinetic energy of the vehicle is transfer to the potential energy of the spring (half shaft). Twisting of this half shaft is depends upon how much torque is induced in the shaft. By using conservation of energy, we can see the kinetic energy eventually becomes equals to the energy comes into the spring.

Torque builds up level ground (Vehicle)

$$T_{w2p} = k_{w2p}\chi_{w2p} = \sqrt{m'v^2 k_{w2p}}$$

$$T\_w2p = min(T\_w2p, T\_s)$$

After calculating the dynamic torque, it is necessary to compare it against the skid torque as skid torque is the highest torque that vehicle can experience. Dynamic torque can't exceed the skid torque.

Torque builds up level ground (motor)

$$T_{m2p} = k_{m2p}\chi_{m2p}\mu 1 = \sqrt{I\omega^2 k_{m2p}}\ \mu 1$$

Dynamic torque coming from the motor is based on the similar idea like the torque from the vehicle. In this case we need to know kinetic energy of rotor and stiffness between rotor and park wheel along with the stiffness of the shaft.

C. Skid Torque

Torque experience by the park wheel when the vehicle skid on the ground. For e.g. suppose the vehicle is parked on a slope and the PLM is disengaged and engaged directly which causes vehicle to move, which is equivalent to one tooth passing on the ratchet wheel. This will make the vehicle accelerate down the slope and gain a certain speed before the PLM stops the vehicle. This situation may happen in two situations, either the vehicle is in the forward direction or it is in the reverse direction. For the skid torque need to know friction between wheel and ground, so the normal force and overturning force on vehicle.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

F – mgsinθ = ma; acceleration at the time of skid

So, Torque on the wheel when vehicle is moving in forward direction can be calculated with

$$T_s = fr = \mu mgr \frac{b\cos\theta}{l - \mu h}$$

Similarly, we can calculate torque on the wheel in reverse direction.

D. Drop in speed

This is the speed of a vehicle at the time of pawl engagement. The potential energy of the road transferred to the kinetic energy of the vehicle. There is an interval for the speed of the vehicle, it's between the vehicle is parked on a slope and parking pawl will hit the teeth of the ratchet wheel. The maximum the ratchet wheel can rotate before the pawl will stop the vehicle is 360° through the number of teeth on the ratchet wheel. This will result in a certain distance of travel before the vehicle will stop. This distance and the acceleration down the hill will be a result of a certain velocity just before the pawl will stop the vehicle. Also, a maximum speed is required so that the transmission doesn't break when the parking pawl is engaged. Over a certain velocity the parking pawl will start ratcheting if it's engaged over this velocity.

$$mgh = \frac{1}{2}m'v^2$$

Solving the equation can help us to estimate the drop in velocity when the vehicle is on the ramp

E. Rolling Distance

The distance up to which vehicle can roll during blocked position of the pawl to the engaged position of the pawl when vehicle is on the ramp. This distance is different based on the park system installed. (Forward rolling and rearward rolling). For calculation purpose, we are assuming the symmetric conditions.

$$S_R = \left(\frac{\gamma}{u} + \frac{mgr\sin\theta}{k_w} + \zeta\right)r$$

IV. PARK LOCK EVALUATION TOOL

Figure 4 Park Lock Mechanism Evaluation Tool Build in VBA

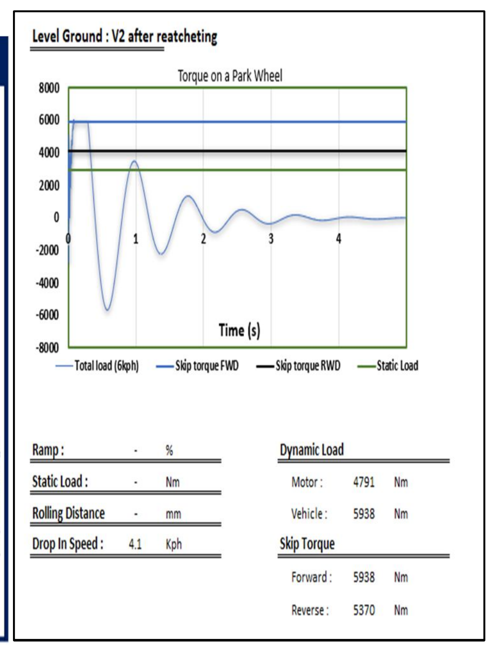

Figure 5 Post ratcheting drop in speed

Fig.4 derives the structure created to evaluate park lock mechanism using Excel-VBA. To perform the calculations, it needs number of inputs from vehicle side, EDU side and if the vehicle is with towing trailer, then the trailer's inputs are also necessary. Outputs are categorized in four sub parts, i.e. With and Without trailer when vehicle is on the ramp and upper and lower limit of post dropping speed when the vehicle is on the level ground.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

Vehicle Input	**Electric Drive Unit Input**
Curb Weight	Motor inertia
Gross Vehicle Weight	Gear Ratio from Rotor to park wheel
Gross Trailer Weight	Gear Ratio from Park wheel to output
Mass of tire	Park wheel tooth pitch
Mass of wheel	Wheel to park wheel lash
Mass of brake rotor	Rotor to park wheel stiffness
Inertia of tire	**Trailer Input**
Inertia of wheel	Max trailer load
Inertia of brake rotor	Max load on tow hitch
Tire radius	Tow hitch
Combined stiffness of half shafts	Distance of tow hitch to vehicle rear axle
Wheelbase	Distance of tow hitch to axle
CG height	Grade of ramp for Vehicle
Weight distribution ratio (Front/Total vehicle)	
Tire to ground friction coefficient	
Grade of ramp	
Lower Bound / Upper Bound	

Figure 6 Inputs require to perform the calculations

When the vehicle is on the level ground, to estimate the drop in speed it needs an additional input apart from the listed in Fig. 5 Those additional inputs are nothing but the design parameters of park lock mechanism like, Cradle, finger and carriage length, reaction lengths, preload, and stiffness of the springs. Also, Interaction arm length of Park pawl, preload, and stiffness of the spring at pawls pivot point. With the help if these design parameters we can able to estimate post ratcheting drop in speed as shown in Fig.5. Post ratcheting speed of a vehicle in case of level ground is shown in Fig. 5 apart from dynamic loads and skip torque. 4.1 Kph is the drop in speed with 5938 Nm is the max load that wheel can experience in this situation. Graphical representation is for toque on the park wheel is shown with respect to time.

V. 3D SIMULATION OF PARK LOCK

When it comes to simulating such kind of complex mechanisms along with dynamic behaviours of the system. MSC - 'ADAMS' is the one of the best choices. As 'ADAMS' is the world's most famous and widely used Multibody Dynamics (MBD) software, Adams improves engineering efficiency and reduces product development costs by enabling early system-level design validation. Engineers can evaluate and manage the complex interactions between disciplines including motion, structures, actuation, and controls to better optimize product designs for performance, safety, and comfort. Along with extensive analysis capabilities, Adams is optimized for large-scale problems, taking advantage of high-performance computing environments. These advantages drive us to perform this simulation in "ADAMS'.

1) *ADAMS Modelling Approach*: A dynamic simulation analysis model established using a parasolid file and ADAMS. There are 29 constraints, comprising 5 revolving joints, 15 fixed joints and 1 translational joint and 3 spherical joints and 5 primitive joints. A translational spring–damper, a rotational spring–damper and some necessary contacts are established in the model.
2) *Load Case Setup*: Park wheel, vehicle, and motor inertia; initial rotational speed set equivalent to 8 Kph. Resistive torque applied for deceleration of speed. Initiate the park lock after specific time interval to avoid initial chattering.
3) *Contact Modelling*: Contacts allow you to model how free-moving bodies interact with one another when they collide during a simulation. Models' friction effects at the contact locations using the Coulomb friction model to compute the frictional forces. The friction model in contact models dynamic friction but not stiction. Use damping when you specify the impact model for calculating normal forces. Damping defines the damping properties of the contacting material. You should set the damping coefficient is about one percent of the stiffness coefficient. Use friction transient velocity in the coulomb friction model for calculating frictional forces at the contact locations. The integrator statement to select an integrator when you choose to perform a dynamic analysis. The dynamic analysis of a mechanical system consists essentially of numerically integrating the nonlinear differential equations of motion. GSTIFF is the most widely used and tested integrator in Adams Solver It is a variable-order, variable-step and multi-step integrator with a maximum integration order of six. The BDF coefficients it uses are calculated by assuming that the step size of the model is mostly constant. Thus, when the step size changes in this integrator, a small error is introduced in the solution. High speed, High accuracy of the system displacements, Robust in handling a variety of analysis problems are the advantages of using GSTIFF. Prefer SI2 formulation as SI2 (Stabilized-Index Two) is an equation formulation technique that can be used for equations describing mechanical systems. SI2 will gives very accurate results, especially for velocities and accelerations. Usually allows an ERROR that is approximately 10 to 100 times larger than regular GSTIFF to produce the same quality of results. Tracks high frequency oscillations very accurately.

4) *ADAMS Results*: Pawl is engaged in the park wheel speed of the vehicle is about 4.37 Kph and torque developed on the wheel at the same instant is about 5880 Nm.

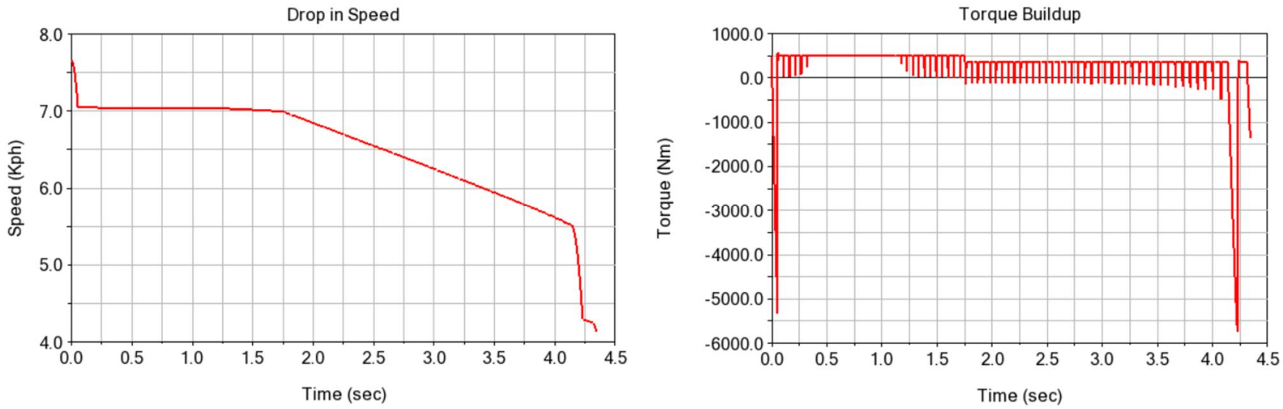

Figure 7 ADAMS Results Output

Above figures are the results output from ADAMS, Torque builds up is about 5880 Nm and which is at the instance where pawl is engaged, and no more further ratcheting is happening

VI. EXPERIMENTAL SETUP

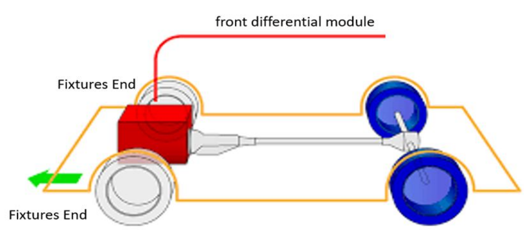

Figure 8 Schematic representation of Test up

Note: Original test set up images are not published here because of Intellectual property rights.

The front differential module was mounted in a fixture with wheels and height similar to the gross vehicle weight. PLA commanded to engage position at vehicle speed 8 km/h. Vehicle speed, drive shaft torque and PLA feedback line were monitored during test to evaluate the drop in speed of park pawl and the torque acting at the test object. The drop in speed and torque acting at the test object when park pawl engages at park ring gear wheel was evaluated for the sets of test objects. The test object was driven for 20 minutes at a vehicle speed of 60 km/h to lubricate the system.

Test Object No	Direction	Drop In Speed (Km/h)	Total Torque (Nm)
1	FWD	4.6	5806
2	FWD	4.6	5790
3	FWD	4.3	5820
4	FWD	4.1	5955
5	FWD	4.2	5880
6	FWD	4.6	5810
7	FWD	4.3	5961
8	FWD	4.5	5940
9	FWD	4.2	6022
10	FWD	4.3	5910
11	FWD	4.2	5875
12	FWD	4.4	5901
13	FWD	4.2	5870
14	FWD	3.7	5815
15	FWD	3.9	5992
Avg		4.3	5890
Max		4.6	6026
Min		3.7	5795

Figure 9 Collection of Test Samples

VII. RESULTS AND DISCUSSION

Average Drop in speed from test was 4.3 Kph. Comparing this speed with ADAMS simulation gives results within 4 % variation range. Drop in Speed from the simulation is about 4.4 Kph. Which is close to test results and also within the range of test set up Drop in speed output from 1D evaluation tool is 4.1 Kph, which is also close to the test results and within 7 % of variation range. Fig. 9 can give us an idea, that results from the Adams simulation and from the 1D evaluation tool are very much comparative to the test results for Drop in speed at the time of pawl engagement when the vehicle is on the level ground.1D evaluation tool is very much comparative to the test results for Drop in speed at the time of pawl engagement when the vehicle is on the level ground that can be acceptable. As mentioned above ADAMS results and varying within 4% and 1D results are within 7% of range.

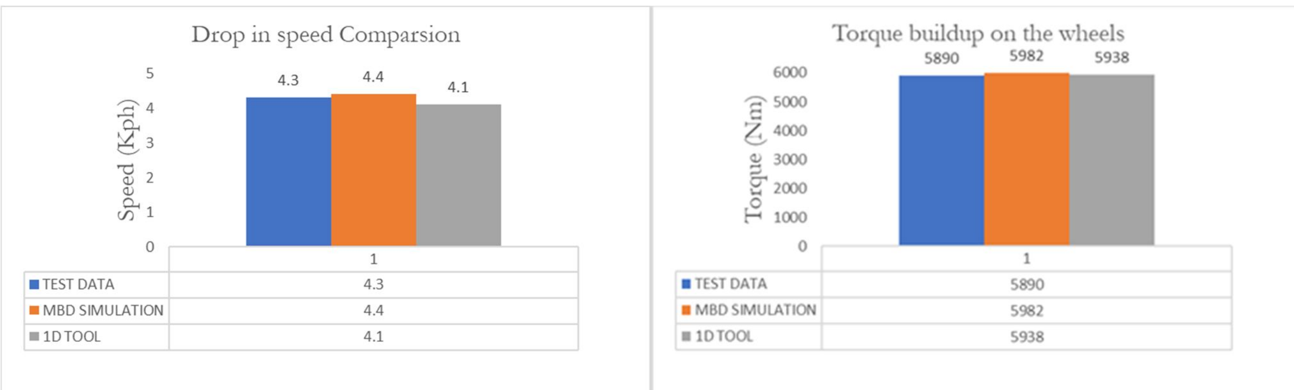

Figure 10 Drop in speed and Torque builds up results summary

VIII. CONCLUSION

This study has made several contributions to understanding of the parking pawl mechanism. Mandatory requirements on the design and approval of this key device were reviewed and a detailed dynamic model was successfully developed in ADAMS. Application of proper solver settings, elastic body, damping and contact formulations are all important aspects of the modeling. Simulation results for the engagement speed, accelerations, and torque build up during the event are having very good correlations to those obtained from the bench tests. 1D Evaluation tool is developed from designer point of view. Tool covers with preliminary results output that can help design engineer to estimate the loads at early stage of design. Results from the 1D tool like Drop is speed and torque build up in rearward and forward directions are also having a good correlation with the test data. Another aspect from the tool is that we can iterated the results just by changing the input parameters within a short amount of time.

IX. NOMENCLATURE

m – vehicle mass
m' – equivalent dynamic mass, including vehicle mass and spinning inertia
v – vehicle drop-in speed
u_1 – gear ratio from rotor to park wheel
u_2 – gear ratio from park wheel to output
v – vehicle drop-in speed
k_{w2p} – wheel to park wheel torsional stiffness
χ_{w2p} – wheel to park wheel twist angle
I – motor rotor inertia
ω – rotor spin speed
k_{m2p} – rotor to park wheel torsional stiffness
χ_{m2p} – rotor to park wheel twist angle
u2 - Gear Ratio from Rotor to park wheel
θ– ramp angle
I_m – motor rotors inertia
I_a – axles inertia, including diffs, half shafts, brake rotors, wheels and tires
u – geartrain total ratio

r – tire rolling radius
γ – park wheel pitch angle
k_w2p – wheel to park wheel torsional stiffness
χ_w2p – wheel to park wheel twist angle
k_w – drive train stiffness from wheel to park wheel
ζ – drive train lashes reflected on wheel

REFERENCES

[1] Roy, N. and Ba, J., "Design, Analysis and Optimization of Parking Pawl Mechanism using ADAMS," SAE Technical Paper 2019-01-0336, 2019. https://doi.org/10.4271/2019-01-0336.
[2] Yuan, C. and Rahman, N., "Park Pawl Dynamic System Engagement Speed Calculation Using Isight," SAE Technical Paper 2015-01-1363, 2015, https://doi.org/10.4271/2015-01-1363.
[3] Jeyakumaran, J., and Zhang, N., "Dynamic Analysis of an Automatic Transmission Parking Mechanism," presented at ICTAM 2008, Australia, 2008.
[4] Rasmus Andersson "CAE Tool for Evaluation of Park Lock Mechanism in a DCT Transmission" https://www.diva-portal.org/smash/
[5] Transmission parking Pawl - my AutomaticTransmission.com (no date) Available at: http://estimate.myautomatictransmission.com/transmission-parkingpawl/
[6] Karthik Swami Narayan "Park Lock Development" https://odr.chalmers.se
[7] "Torque Converter, CVT, Dual Or Single Clutch Autos, What's The Difference?". CarsGuide. N.p., 2017. Web. 2 May 2017. https://www.carsguide.com.au/car-advice/torque-converter-cvt-dualor- single-clutch-autos-whats-the-difference-33411
[8] MSC, "Adams User Manual," 2019.
[9] Huang, Y. (no date) 'Park Lock Analysis using VALDYN', Ricardo Inc, Advanced Systems Engineering