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VIRTUAL HOMOLOGATION FOR ABS SYSTEM

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Abstract-

Homologation is a certification process of any product like vehicle to make it comply with the standards and legal requirements of different markets. There are predefined standards for homologating different parts and systems of an automobile. homologation is mandatory for all vehicle models and their variants as per the standards. Antilock braking system (ABS) must be homologated as per standard IS 11852 (Part 9). Homologation process consumes lot of cost and human effort for an organization. To reduce the cost and effort, virtual homologation is a process followed by manufacturers to homologate the vehicles in a simulation environment. This process of virtual homologation is followed by AIS, UN/ECE and FMVSS standards. This supports in reducing the human effort and cost involved in real vehicle homologation. For performing virtual homologation, the standards mention that the simulation environment behavior should be closer to real vehicle. The simulation environment is compared with real vehicle and validated. Appropriate improvements to plant model are made to bring simulation results closer to real vehicle. The current work aims at reducing the gap between the behavior of a real vehicle and a simulated plant model. This is achieved by finding the difference in dynamic behavior of both simulation and real vehicle environment and identifying the simulation parameters to be tuned. These parameters are tuned and validated. Mat lab Simulink environment is used for Simulation.

***Keywords* — ABS Homologation, Virtual Homologation, Simulation and Validation.**

I. INTRODUCTION

Antilock braking system (ABS) is a safety system used in vehicles to avoid wheels from locking. This system intervenes when the loss of traction occurred and increases the steerability of the vehicle while braking. Homologation is the process of certifying that a particular vehicle is roadworthy and matches certain specified criteria laid out by the government for all vehicles made or imported into that country. In order to sell a vehicle in a specific market, the manufacturer must approve or confirm officially that it meets or exceeds all applicable regulatory standards and specifications.

In India, the standards are given by Automotive Research Association of India (ARAI) or the Vehicle Research and Development Establishment (VRDE). Virtual homologation for vehicles uses software and mathematical models to replicate different scenarios of vehicle behaviors, and to ensure that vehicles comply with global safety regulations. Virtual testing is correlated with physical testing results to ensure vehicle parameters and finely tuned to reduce cost in real vehicle testing. Virtual homologation is the processusing simulation environment. Simulation tool application constitutes of a vehicle dynamic model whose subsystems and the environment affecting the vehicle can be configured by parameters. The parameters can be used to customize the vehicle dynamics model to suit different vehicles. The environment parameters like road dimensions and track friction are also defined to completely define the simulation scenario.

II. ABS HOMOLOGATION

A. Vehicle Specification

Fig. 1. TATA LPT 3118

The real vehicle considered for research work is shown in Fig.1.The specification of a vehicle is given in Table 1.

TABLE. 1

TATA LPT 3118 SPECIFICATIONS

Vehicle Model	TATA LPT 3118
Power	175bhp
Wheel base	6 m
Fuel tank	365 Ltr
Engine	5883 cc
Axle configuration	6x2
Vehicle category	N3
Maximum speed	80 km/h
System voltage	24v
Gearbox	6-Speed
Max Torque	700Nm
Brake	Air brakes (type = drum brakes)

Vehicle	Front	Rear
Track Width 'mm'	2076	1860

Weight Details	Unladen	Laden
GVW ‘kgs’	8150	30650
FAW ‘kgs’	4460	7330
RAW ‘kgs’	3690	23320
C.G. height ‘m’	0.843	1.781

In ABS homologation the real vehicle parameters are taken from the test report. Tire circumference, track width, geometric parameters, etc. are parameterized in simulation tool vehicle model. Then the maneuvers are created as per standards [5]. In this track creation the coefficient of friction for each wheel, maximum vehicle velocity, acceleration and braking of vehicle, track properties, etc. are configured. Then it is simulated.

B. Dynamic – ABS Performance Test

1. Adhesion Utilization Test

Adhesion is the ability of a vehicle's tire to stick firmly to the road. Adhesion utilization test is performed to check how much friction is utilized. High friction means the steerability is increased and braking distance is decreased. During ABS operation, the pressure modulation works with the brake modulator, the pressure is quickly applied and released at the wheels. This is called pressure modulation, which works to prevent the wheels from locking. The ABS system can modulate the pressure to the brake as often as 15 times per second. ABS precisely controls the slip rate of the wheels to ensure maximum grip force from the tires and therefore ensures easy maneuver and stability for the driver of thevehicle. The target slip rate can be from 10% to 30%. Zero percentage slip means the wheel is rolling freely, while 100 %means the wheel is fully locked. A slip rate of 25 % means the velocity of a wheel is 25% less than that of a freely rolling wheel at the same vehicle speed. The main aim is to increase the braking efficiency. In this test how much adhesion is utilized while the vehicle is running indifferent condition will be found.

To satisfy the test, adhesion utilized should be greater than 75%. This test is performed with standard IS 11852 (Part 9) [5].

a) Braking without Controller

Braking without ABS controller is performed to estimate adhesion. In simulation tool, the vehicle model is parameterized as same as real vehicle [TML LPT 3118] and as per standards the maneuvers are created in the simulation tool. After this simulation is performed, the MATLAB file (m) is generated, taking this file as the input plant model which is the MATLAB test environment. Here the m file is compiled and the output is obtained. The test environment runs without ABS controller which is in normal braking condition.

b) Braking with Controller

Braking with ABS controller is performed to measure how much adhesion is utilized. After parameterization as same as real vehicle, the simulation is performed. The generated (.m) file is given as input to closed loop test environment in MATLAB Simulink model. Here both plant model and ECU (ABS Controller) shares the information like pressure, speed, etc. where the end of line parameter is the input to the controller (end of line parameter is used to make ECU to understand in which vehicle it is fitted. Parameters like wheel base, Centre of gravity, physical parameters, etc. are parameterized in this as same as real vehicle). Therefore, in this closed loop test environment during braking ABS will intervene and then the result is generated through output.

c) Test case - Dry asphalt - Unladen condition

The coefficient of adhesion (k) is determined as the quotient ofthe maximum braking forces without locking the wheels and corresponding dynamic load on the axle being braked. As per the standard [5], the brakes are applied when only one of the axles of the vehicle under test, at an initial speed of 50 km/h. The braking forces are distributed between the wheels of the axle to reach maximum performance. Thus, to find the maximum performance of each axles, it is tested in front and rear axle are in failed conditions.

Inputs required for laden and unladen condition are
P= Total vehicle mass in (kg)
F_1= Front axle weight in (N)
F_2= Rear axle weight in (N)
H= Centre of gravity height in (m)
E= Wheel base in (m)
J= Deceleration of vehicle (m/s^2)
g= Acceleration due to gravity (9.81 m/s^2)
(1) Pre-condition:
- Vehicle is in the Unladen condition
- Surface = Dry asphalt

(2) Test Procedure:

Rear axle is in fully failed condition
- ABS is disconnected
- Initial speed is 50 km/h
- Non-ABS braking at 50 km/h with rear axle is in fully failed condition
- Note the minimum measured value of time for speed to reduce from 40 to 20 km/h in seconds [many trials are conducted, select 3 values of time within t_{min} and 1.05 t_{min}]
- Calculate Mean time (tm) from 3 trials
- Calculate Mean braking rate (z_m)[v = u + at, z = J/g, a = zg]

$$z_m = 0.566 / t_m \quad (1)$$

- Dynamic Force of Front axle

$$F_{fdyn} = F1 + (P.\ z_m.\ g.\ h) / E \quad (2)$$

- Calculate Coefficient of adhesion for the front axle (k_f)

$$k_f = [(P.\ z_m.\ g) – (0.015\ F_2)] / [\ F_1 + (P.\ z_m.\ g.\ h) / E] \quad (3)$$

Front Axle fully failed condition
- Non-ABS braking at 50 km/h with front axle fully failed condition
- Note the minimum measured value of time for speed to reduce from 40 to 20 km/h in seconds [many trials are conducted, select 3 values of time within t_{min} and 1.05 t_{min}]
- Calculate Mean time (t_m) from 3 trials
- Calculate Mean braking rate (z_m)[v = u + at, z = J/g, a = zg]

$$z_m = 0.566 / t_m \quad (4)$$

- Dynamic Force of Rear axle

$$F_{rdyn} = F2 – (P.\ z_m.\ g.\ h) / E \quad (5)$$

- Calculate Coefficient of adhesion for the rear axle (k_r)

$$k_r = [(P.\ z_m.\ g) – (0.010\ F_1)] / [\ F_2 – (P.\ z_m.\ g.\ h) / E] \quad (6)$$

ABS is connected
- Initial speed is 55 km/h
- ABS braking at 55 km/h
- Note the minimum measured value of time taken for speed to reduce from 45 to 15 km/h in seconds [many trials are conducted, select 3 values of time within t_{min} and 1.05 t_{min}]
- Calculate Mean time (t_m) from 3 trials
- Calculate Maximum braking rate (z_{AL}) using the formula

$$z_{AL} = 0.849 / t_m \quad (7)$$

Calculate Normal reaction of road surface under dynamic conditions with the anti-lock system operative (F_{fdyn}) using the formula

$$F_{fdyn} = F1 + (P.\ z_{AL}.\ g.\ h) / E \quad (8)$$

- Calculate Total normal dynamic reaction of road surface on the axle(s) of semi-trailer or center-axle trailer (F_{rdyn}) using the formula

$$F_{rdyn} = F2 – (P.\ z_{AL}.\ g.\ h) / E \quad (9)$$

- Measure Coefficient of adhesion (k_M)

$$k_M = (k_f.\ F_{fdyn} + k_r.\ F_{rdyn}) / P.\ g \quad (10)$$

- Measure Adhesion utilization (∈)

$$\in = z_{AL} / k_M \quad (11)$$

- If ∈ > 1.00 the measurements of coefficients of adhesion shall be repeated. A tolerance of 10 % is accepted.

(3) Expected result
- Coefficient of adhesion (k_M) should be ~ 0.8
- Adhesion utilization (∈) should be > 75%

This is the test case for Dry asphalt- unladen condition. The same test case is followed for Wet basalt – unladen condition, the only difference is the Surface and Coefficient of adhesion should be < 0.3.

d) Results - Dry asphalt - Unladen condition

The test results conducted on dry asphalt road with unladen condition is shown in Fig 2.

Fig. 2. Logs

The output logs are given in Table 2.

TABLE. 2

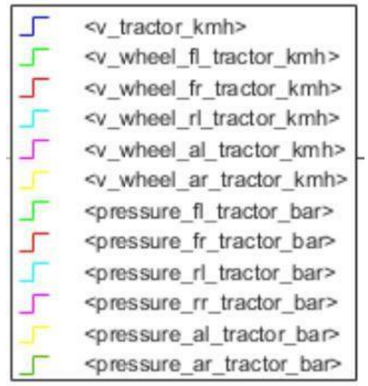
OUTPUT LOGS

<v_tractor_kmh>	Truck velocity in km/h
<v_wheel_fl_tractor_kmh>	Truck Front Left wheel speed in km/h
<v_wheel_fr_tractor_kmh>	Truck Front Right wheel speed in km/h
<v_wheel_rl_tractor_kmh>	Truck Rear Left wheel speed in km/h
<v_wheel_al_tractor_kmh>	Truck Additional axle Left wheel speed in km/h
<v_wheel_ar_tractor_kmh>	Truck Additional axle Right wheel speed in km/h
<pressure_fl_tractor_bar>	Front Left brake pressure in bar
<pressure_fr_tractor_bar>	Front Right brake pressure in bar
<pressure_rl_tractor_bar>	Rear Left brake pressure in bar
<pressure_rr_tractor_bar>	Rear Right brake pressure in bar
<pressure_al_tractor_bar>	Additional axle Left brake pressure in bar
<pressure_ar_tractor_bar>	Additional axle Right brake pressure in bar

These are the output scope from the MATLAB simulation

(1) Rear Axle fully failed condition

In rear axle failed condition, both rear axle and additional axles are failed. This is done in simulation tool vehicle model by changing the parameter value of brake coefficient (Brake torque produced for unit pressure) (Nm/bar) of driven and additional axles as zero. So that the brake pressure is supplied only to front axle brakes and braking is applied in front axle. With Several trial and error method, the exact pressure 6.1bar is found where the front axle wheels are not locked. Here the time (tm) is obtained. Then z_m and k_f are calculated. The Vehicle model (TML 3118) is parameterized and simulated with created maneuver. The vehicle speed is increased gradually, at 50 kmph Non – ABS sudden braking is done. The full load is shifted to front wheels. Wheel lock may occur below 20 km/h (IS 11852(Part 9)) [5]. Here rear axle and additional axle is failed, so there is no brake



pressure is supplied. At pressure of 6.1 bar and higher, during braking without controller front axle wheels are locked above 20km/h.So, the brake pressure is decreased. At 6 bar front axle wheelsare not locked. But the exact pressure must be identified. At 6.1 bar pressure it is satisfied as shown in Fig. 3, here front axle is braked whereas rear and additional axles are not braked and Rear Axle failed condition Result (Dry asphalt Surface) is given in TABLE 3.

TABLE.3

REAR AXLE FAILED CONDITION RESULT (DRY ASPHALT SURFACE)

Brake Pressure (bar)	Front Axle Wheels
6.5	Lock
6.11	Lock
6	No lock
6.1 (exact pressure)	No lock

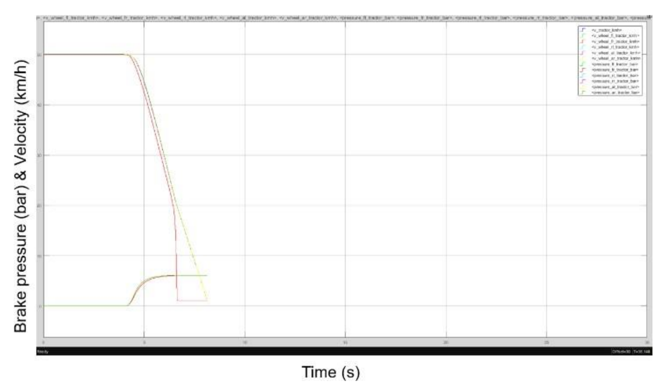


Fig. 3. Exact Brake Pressure = 6.1 bar (Dry – Rear axle failed)

(2) Front axle failed condition

In front axle failed condition, front axle is failed. This is done in simulation tool Vehicle model by changing the parameter value of brake coefficient (Nm/bar) of steering axle as Zero. So that the brake pressure is supplied only to rear and additional axle brakes and brakes are applied. With Several trial and error method, the Exact pressure 2.17 bar is found where the rear axle wheels are not locked. Here the time (tm) is obtained. Then zm and kf are calculated. Non – ABS sudden braking at 50 kmph. Wheel lock may occur below 20 km/h (IS 11852(Part 9)) [5]. Here front axle is failed, so there is no brake pressure is supplied to front. At pressure of 2.18 bar and higher, during braking without controller the rear and additional axle wheels are locked above 20km/h. So, the brake pressure is decreased. At 2.16 bar rear axle wheels are not locked. But the exact pressure must be identified. At 2.17 bar pressure it is satisfied as shown in Fig. 4, here rear and additional axles are braked, due to load transfer during braking rear axle wheels are locked before additional axle. So, additional axle brake pressure is checked, and the exact pressure is found. Front axle is not braked and follows the vehicle speed. Then time difference between vehicle velocity and wheel speed is calculated in seconds.

lows the vehicle speed. Then time difference betweenvehicle velocity and wheel speed is calculated in seconds.

Brake Pressure (bar)	Rear and Additional Axle Wheels
5	Lock
2.18	Lock
2.16	No lock
2.17 (exact pressure)	No lock

TABLE 4

FRONT AXLE FAILED CONDITION RESULT (DRY ASPHALT SURFACE)

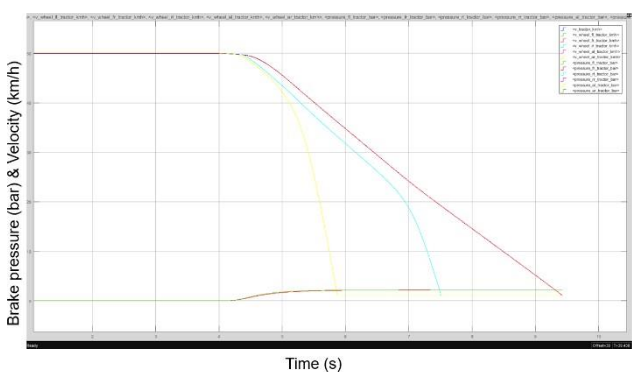


Fig. 4. Exact brake Pressure = 2.17 bar (Dry – Front axle failed)

The front axle failed condition result (dry asphalt surface) is given in Table 4.

(3) ABS Braking

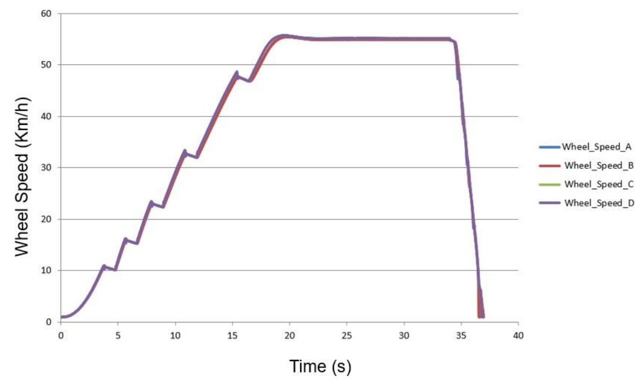


Fig. 5. Wheel Speed (Dry asphalt – ABS braking)

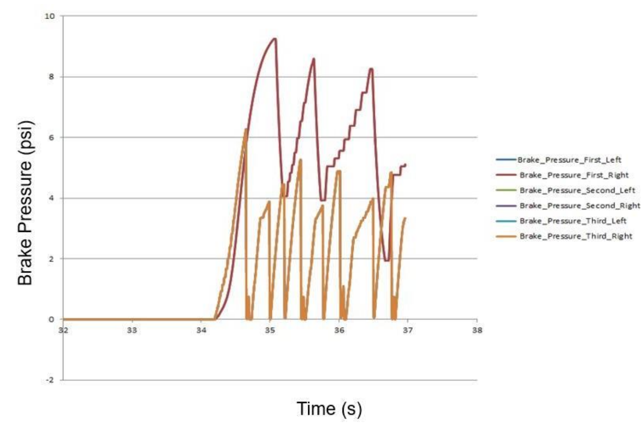


Fig. 6. Brake Pressure (Dry asphalt – ABS braking)

In Fig. 6, ABS pressure modulation is occurred during ABS braking. Front brake pressures are high because of brake balance for loading conditions. During braking the load shifts to front axle. Thus, the difference in brake pressure.

e) Results – Wet Basalt - Unladen condition

(1) Rear Axle fully failed condition

TABLE 5

REAR AXLE FAILED CONDITION RESULT (WET BASALT SURFACE)

Brake Pressure (bar)	Front Axle Wheels
5	Lock
1.63	Lock
1.61	No lock
1.62 (exact pressure)	No lock

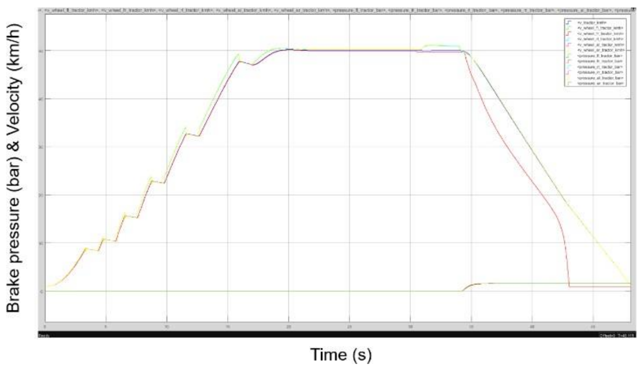


Fig. 7. Exact brake Pressure = 1.62 bar (Wet – Rear axle failed)

In this rear axle failed condition, there is no supply of pressure to rear and additional axle wheels. So, the minimum pressure is supplied to front axle and the exact pressure is found wherethe wheels are not locked. Then the time is obtained.

(2) Front axle failed condition

In this front axle failed condition, there is no supply of pressure front axle wheels. So, the minimum pressure is supplied to rear and additional axle. Then exact pressure is found where the wheels are not locked. Then the time is obtained.

TABLE 6

FRONT AXLE FAILED CONDITION RESULT (WET BASALT SURFACE)

Brake Pressure (bar)	Rear and Additional Axle Wheels
4.5	Lock
0.9	Lock
0.7	No lock
0.8 (exact pressure)	No lock

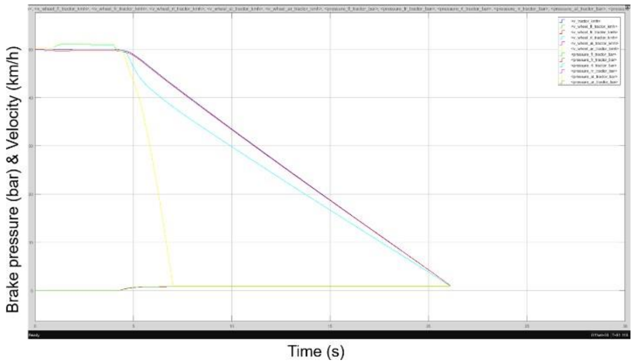


Fig. 8. Exact brake Pressure = 0.8 bar (Wet – Front axle failed)

(3) ABS Braking

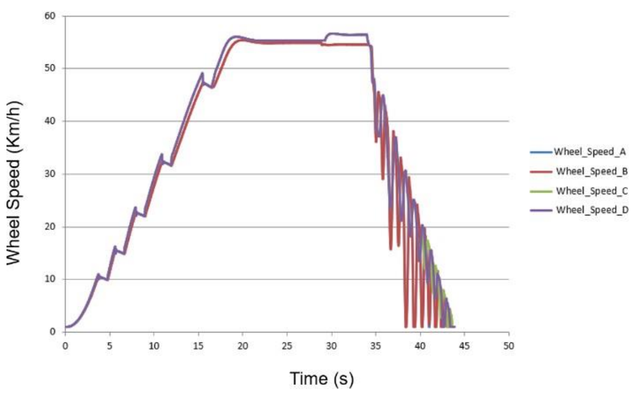


Fig. 9. Wheel Speed (Wet basalt – ABS braking)

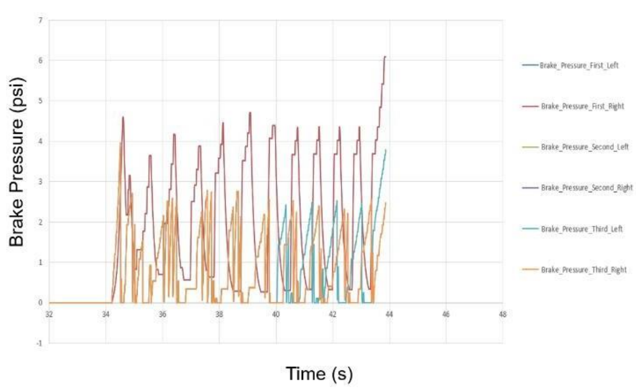


Fig. 10. Brake Pressure (Wet basalt – ABS braking

f) Comparison between Real vehicle test report and the Simulation result

TABLE 7

TATA 3118 TEST REPORT

Test Report					
Non ABS braking at 50 km/h with REAR axle failed condition					
Surface	t_m in sec			Z_m	K_f
Dry asphalt	1.917			0.295	0.486
Wet Basalt	4.837			0.117	0.194
Non ABS braking at 50 km/h with FRONT axle failed condition					
Surface	t_m in sec			Z_m	K_r
Dry asphalt	1.73			0.33	0.80
Wet Basalt	6.02			0.09	0.20
ABS braking at 55kmph:					
Surface	t_m in s		Z_{AL}	F_{fdyn}	F_{rdyn}
Dry asphalt	1.450		0.586	5202	3008
Wet Basalt	4.770		0.178	4734	3476
Results					
Surface	K_M		e		Result
	Measured	Spec	Measured(%)	Spec (%)	
Dry asphalt	0.60	~0.8	97	>75	Passed
Wet Basalt	0.20	<0.3	90	>75	

TABLE 8

SIMULATION RESULTS

Simulation						% diff
Non ABS braking at 50 km/h with REAR axle failed condition						
Surface	t_m in sec			Z_m	K_f	t_m
Dry asphalt	1.287			0.439	0.710	39 %
Wet Basalt	5.097			0.111	0.182	5.2 %
Non ABS braking at 50 km/h with FRONT axle failed condition						
Surface	t_m in sec			Z_m	K_r	t_m
Dry asphalt	1.914			0.296	0.707	10 %
Wet Basalt	6.714			0.084	0.178	10.9%
ABS braking at 55kmph						
Surface	t_m in s		Z_{AL}	F_{fdyn} in Kg	F_{rdyn} in Kg	t_m
Dry asphalt	1.365		0.622	5173	2978	6 %
Wet Basalt	6.200		0.14	4682	3528	26 %
Results						
Surface	K_M		e		Result	e
	Measured	Spec	Measured(%)	Spec (%)		
Dry asphalt	0.71	~0.8	88	>75	Passed	18 %
Wet Basalt	0.18	<0.3	77	>75		13 %

Comparison between Real vehicle test report and the Simulation result is shown in above Table. 7 & 8. Thus, the real vehicle test report is compared with simulation result. There are some % differences between test report and simulation result. This is because there are some parameters like brake coefficient (Nm/bar), bleeding gradient (bar/s) and body damping are not exactly tuned as real vehicle. Then the Environment conditions for real vehicle and simulation isdifferent. Thus, the deviations.

2. Performance on uniform friction surface

Unladen - Dry asphalt

Pre-condition

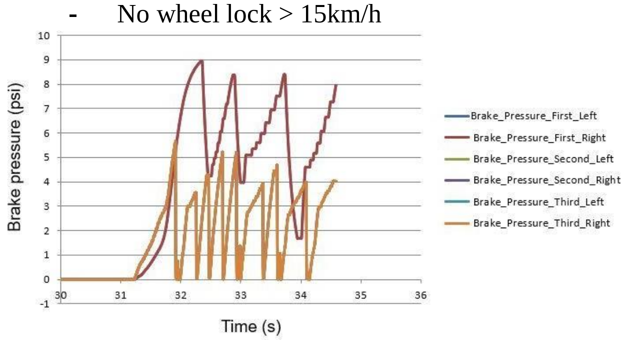
- Engine is disconnected
- Vehicle is in unladen condition
- Coefficient of friction ~ 0.8 (Dry asphalt)
- Initial speed is 40 km/h
- Maximum velocity 80 km/h (Maximum test speed)

Test procedure

- Brakes are applied at initial speed 40 km/hr and at high initial speed as 80% max speed (0.8 Vmax)
- Note the measured speed in Km/h
- Check the stability and steerability

Expected results

- No wheel lock > 15km/h



- Vehicle must be stable
- No deviation from course

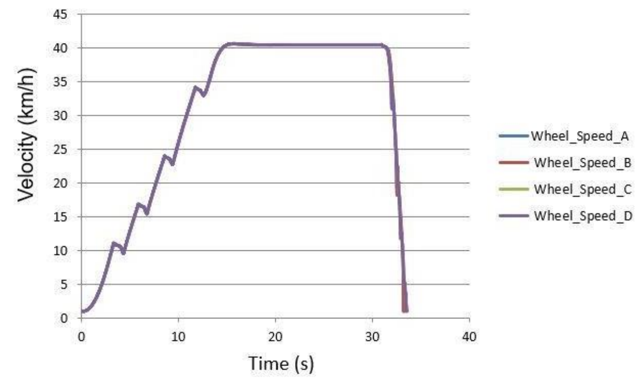


Fig. 11. Wheel speed (Initial speed (40.47 Kmph) – Dry)

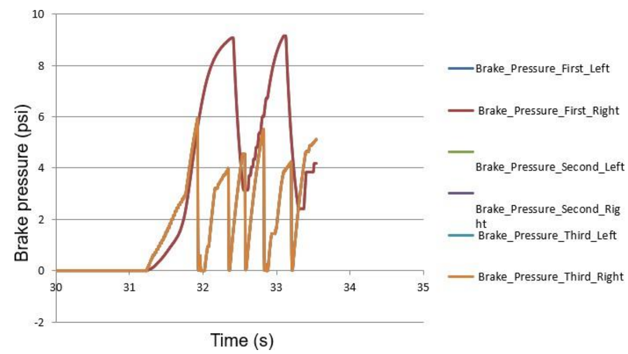


Fig. 12. Brake Pressure (Initial speed (40.47 Kmph) – Dry)

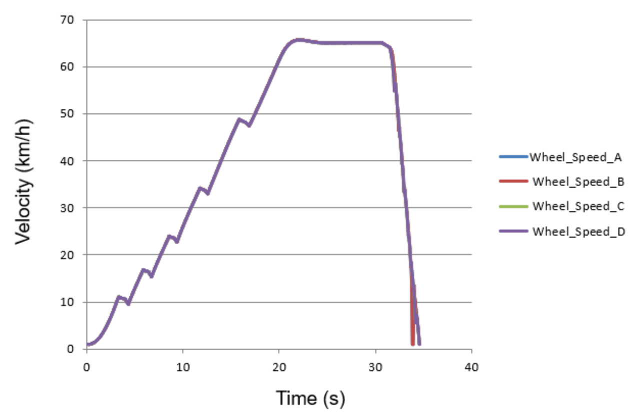


Fig. 13. Wheel speed (Initial speed (65.18 Kmph) – Dry)

Fig. 14. Brake Pressure (Initial speed (65.18 Kmph) – Dry)

From the above graphs, the maneuver is validated as there is no wheel lock till 15 km/h, vehicle stable and no deviation from course.

For Unladen- Wet basalt, same steps are followed like Unladen- Dry asphalt. The only difference is here the surface = wet basalt and speed.

3. Performance during surface transitions

a) Unladen (High to Low)
Pre- condition

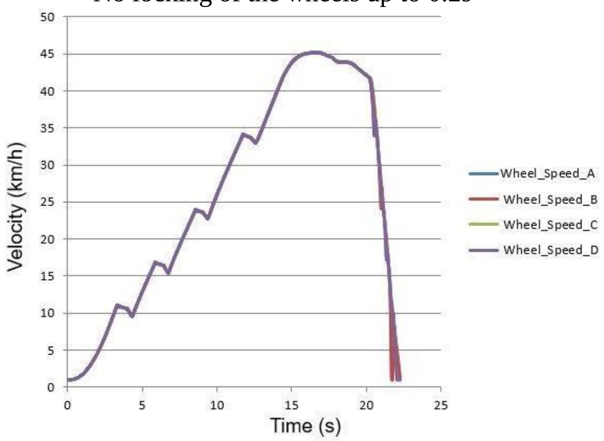
- Engine is disconnected
- Initial speed is 40 km/h
- Maximum velocity 80 km/h (Maximum test speed)
- Vehicle is in unladen

conditionTest procedure

- Brakes are applied at initial speed 40 km/hr and at high initial speed as 80% max speed (0.8 Vmax)
- Tested when an axle passes from a high adhesion surface Dry asphalt (k_H >=0.5) to Low adhesion surface Wet basalt (k_L<=0.3)
- Check the transition

speedExpected result

- No locking of the wheels up to 0.2s



- Vehicle stable, no deviation from course with properadaptation in decelerationFig. 15. Wheel speed (Transition speed (39 km/h) – High to Low)

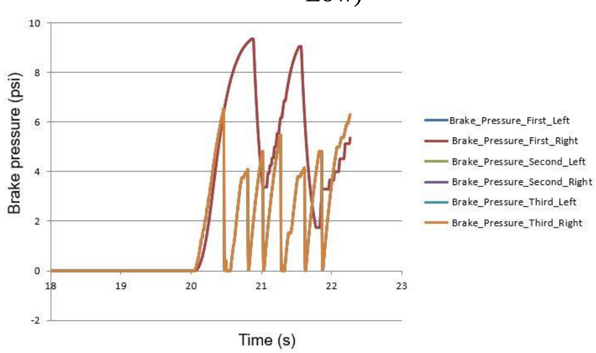


Fig. 16. Brake Pressure (Transition speed (39 km/h) – High to Low)

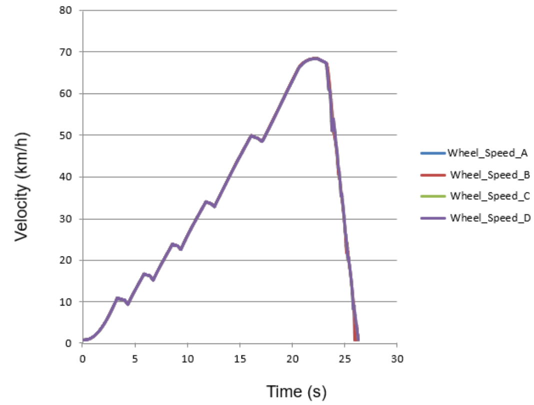


Fig. 17. Wheel speed (Transition speed (63 km/h) – High to Low)

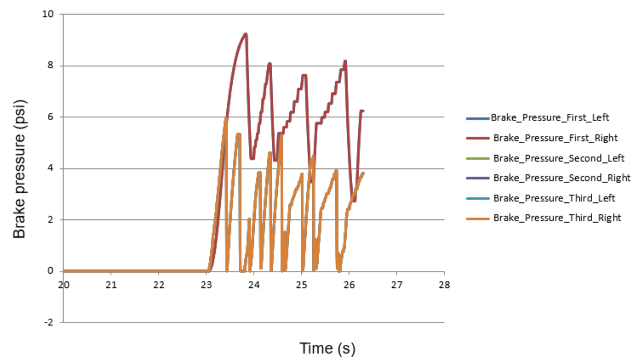


Fig. 18. Brake Pressure (Transition speed (63 km/h) – High to Low)

From the above graphs, the maneuver is validated as there is no wheel locking up to 0.2 secs, vehicle stable and no deviationfrom course.

b) Unladen (Low to High)

Pre- condition

- Engine is disconnected
- Initial speed is 40 km/h
- Maximum velocity 80 km/h (Maximum test speed)
- Vehicle is in unladen condition

Test procedure

- Brakes are applied when an axle passes from a Low adhesion surface Wet basalt (k_L<=0.3) to high adhesion surface Dry asphalt (k_H >=0.5)
- Passage from one surface to other occurs at ~50 km/h or 80% of design speed of the vehicle whichever is lower
- Check the transition speed

Expected result

- No locking of the wheels up to 0.2s
- Vehicle stable

- No deviation from course with proper adaptation indeceleration

Fig. 19. Wheel speed (Transition speed (50 km/h)- Low to high)

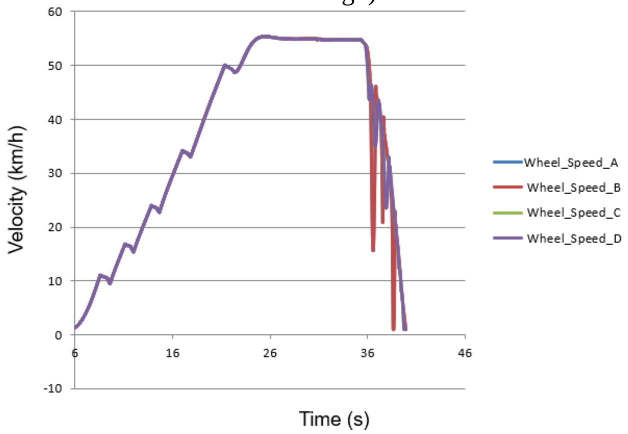


Fig. 20. Brake Pressure (Transition speed (50 km/h)- Low to high)

From the above graphs, the maneuver is validated as there is no wheel locking up to 0.2 secs, vehicle stable and no deviation from course.

4. Performance on differing adhesion surfaces

Pre- condition

- Engine is disconnected
- Vehicle is in unladen condition

Test procedure

- Vehicle pass over the boundary between the high-adhesion surfaces Dry asphalt ($k_H >= 0.5$) and low-adhesion surfaces Wet basalt ($k_L <= 0.3$)
- Brakes are applied at ~50 km/h or 80% of design speed of the vehicle whichever is lower
- Note the speed in Km/h

Expected result

- Vehicle stable
- No deviation from course

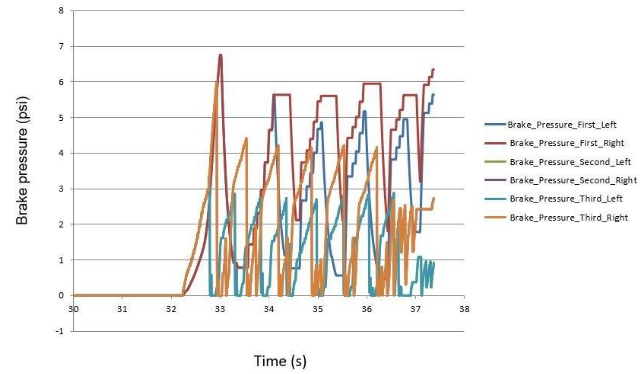


Fig. 21. Wheel speed (Split surface)

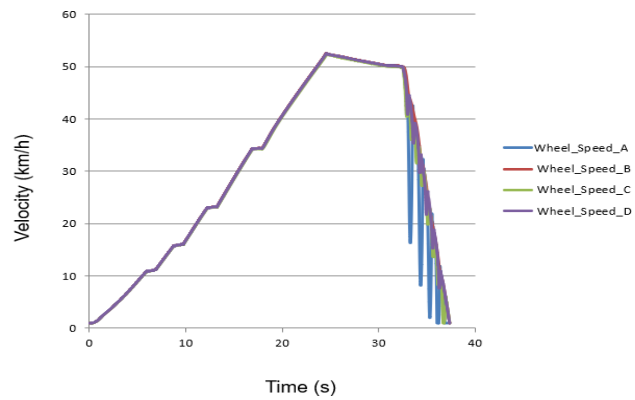


Fig. 22. Brake Pressure (Split surface)

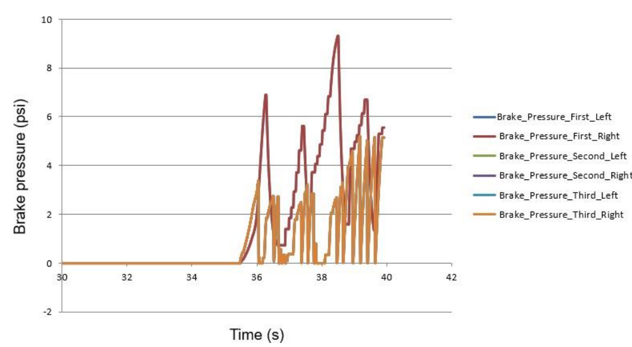


Fig. 23. Yaw rate (Split surface)

From the above graphs, the maneuver is validated as vehicle stable and no deviation from course.

Simulation tool maneuver track width is configured approximately equivalent to real vehicle track width with a small buffer is made in left and right side. Then with this configured maneuver, these performance tests are performed. During simulation the vehicle runs through the track without any deviation. Thus, the vehicle is stable and validated.

III. CONCLUSIONS

This work has paved the way for ABS homologation testing and validating as same as real testing vehicle in the Virtual Environment. This will lead to a faster validating time, reduces the cost, human effort for testing and increasing fuel efficiency. In ABS Homologation, the exact brake pressure is found through simulation. This can be used in real vehicle testing to find the exact brake pressure where the wheels are not locked. Here the testing time is reduced, fuel efficiency is increased and huge cost savings, because the number of times the real vehicle run for testing is decreased. These methods can be followed to other systems to test and validate virtually. So that this can be tested in more efficient manner and the process can be time and cost saving.

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