Development of field test procedure to assess force performances of used tires

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Abstract. Based on United Nation Economic Commission for Europe (UNECE) regulations, there are no existing standard procedures to identify the force performance of used tire which can be physically degraded by time. In vehicle safety, these tire forces in lateral and longitudinal directions are the key factors to response the driver decision during the brake application and maneuver conditions. Therefore, the objective of this research is to develop the used tire performances based on three vehicle testing standards such as brake test, steady-state circular test and severe lane-change test respectively. To assess the tire force performances, two tire categories which are used in those tests with the driving and pedal robot for the sedan vehicle are classified as new tires from 2018 and used tires from 2015, 2014, 2013. To identify tire force performances, various indicators for each test are determined. For example, the standard brake test from UNECE R13H is used to investigate tire friction force in the longitudinal direction. The severe lane-change manoeuvre and steady state circular tests are used to identify the lateral tire force from ISO 3888-2 and ISO 4138 respectively. As a result, it can be concluded that the tire force performances from new and used tires are different based on various indicators.

1. Introduction
The automobile industry is an important sector in developing countries like Thailand. According to the 11th National Economic And Social Development Plan (2012-2016) [1], the automobile industry development is of special interest, especially the parts supplier for domestic and international use. Furthermore, as per the 12th National Economic and Social Development Plan (2017-2021), the government will be establishing the National Automobile and Tire Test Centre. This center can support government policy regarding automobile and parts development [2]. According to United Nations Economic Commission for Europe (UNECE), UNECE R. 117 is set up as a standard for tire testing. This standard test is divided into rolling resistance and wet adhesion [3]. These tire testing standards do not consider the forces in the lateral and longitudinal directions [4]. However, the tire forces are related to vehicle testing standard UNECE r13-h for longitudinal vehicle direction, while the lateral vehicle direction was indicated by ISO 4138 or 3888. [5-7]. At present, tire research for vehicle users focuses mainly on tire parameters affecting the ride and comfort that involves noise, rolling resistance [8,9]. Rolling resistance study indicates in term rolling resistance coefficient while noise test focuses on noise level. However, there are some research that
are related to tire degradation over time [10]. Peel strength and elongation rate determines the level of degradation. However, there are no standard and research works for tire testing that involves a full vehicle model [11]. Thus, the combination of the brake, steady state circular and severe lane-change manoeuvre tests can be used to identify the tire performance based on the tested vehicle. These tests pattern correspond to vehicle dynamics that affects the tires forces in longitudinal and lateral direction. Therefore, the objective of this research is to develop the field test procedure and assess used tire that relates to degradation and tire aging. Furthermore, tire testing is an important thing to do for measuring the tire quality such as performance of the road adhesion to reduce the accidents as well.

2. Methodology
Three different procedures are developed to evaluate tire performance in terms of lateral and longitudinal forces based on vehicle field tests. To identify the tire performance in longitudinal direction, the braking test procedure are developed under UNECE R13-h. For Steady state circular test and severe lane-change maneuver test, the tire performance in lateral direction are involved. Three different tests procedure are described in details below:

2.1. Brake test
The criteria of brake testing of the United Nations Economic Commission (UNECE) is referred as number R13-H (type-0) and is described as the brake performance testing. The brakes have been tested with the vehicle transmission engaged and also disengaged. The vehicle test speed and pedal force are shown in table 1.

| Vehicle Condition        | Test speed | Pedal force |
|--------------------------|------------|-------------|
| Transmission engaged     | 100 km/h   | 80 – 120 N  |
| Transmission disengaged  | 100 km/h   | 80 – 120 N  |

2.2. Steady state circular test
This test is designed to measure the steady state lateral acceleration of the vehicle. The tests are to be conducted as per ISO 4138, on a closed skid pad around a number of marked circles of 8 m radius as shown in figure 1. In this test, the vehicle is required to begin at selected steer angle and run in left turn and accelerate around the prescribed circle. The vehicle stopped acceleration when the it started to deviate from the track. In the actual test, vehicle was selected steer angle at 16 degree for circle 8 m radius.

![Figure 1. Dimension of test track for steady-state circular test.](image)
2.3. **Severe lane-change manoeuvre test**

The severe lane-change manoeuvre is a dynamic procedure of fast transition from the initial straight trajectory to the parallel laterally shifted one, which is next followed by the turn to the trajectory identical with the initial one. The test track on which the severe lane-change maneuver tests were performed was determined according to ISO 3888 standard as shown in figure 2. The initial speed cannot deviate by more than 5 km/h from test speed. Starting from a yaw velocity equilibrium condition, a steering input is applied as rapidly as possible to a preselected value and maintained at that value for several seconds until the measured vehicle motion variables have reached steady state. No change in throttle position can be made, although speed may decrease. In this test, vehicle was running at 40 km/h and 50 km/h. All test runs were performed at least 3 times.

![Figure 2. Dimension of test track for steady-state circular test.](image)

3. **Equipment Preparation**

3.1. **Test vehicle**

The test vehicle used was a passenger car (M1), front engine, front wheel drive (FWD) as shown in Figure 3.

![Figure 3. A sedan type of passenger car and test tires, which was used for this testing.](image)

3.2. **Test tires**

The tires used in the tests was divided into two categories, new tires from 2018 and used tires from 2015, 2014, 2013. New tires were used as benchmarks for performance testing. The size of the tires in this tests was 215/60/R15.

3.3. **Weighing Pad**

To measure the weight distribution of test vehicle on each wheel & axle, the weighing pads was used. The distribution of weight was used to calculate Center of Gravity (C.G.) of the vehicle as shown in Figure 4.
Figure 4. The vehicle weight measurement on weighing pad.

From the above instrument, it is observed that weight on front right and front left wheel was 366 kg and 345.5 kg respectively, and weight on rear right and rear left wheel was 235 kg and 211 kg respectively. Gross weight of vehicle is 1157.5 Kg.

3.4. Systems for Motion Measurement

Inertial Measurement Unit is used for motion measurement during the testing. This unit provides highly accurate measurements of velocity, pitch, roll, and yaw, using three yaw rate sensors and three accelerometers. IMU was calibrated by the manufacturer. It is located at ±20 cm away from the center of gravity (C.G.) as shown in Fig 5.

Table 2. Specification of instrumentation used in tests

| Instrument                  | Quantity          | Measurement range                  | Measurement accuracy |
|-----------------------------|-------------------|-----------------------------------|----------------------|
| Gyroscope Kyowa G-SAT-A-900 | Yaw rate          | ±15.71 rad/s (±900 deg/s)         | ±0.5%                |
| Triaxial Accelerometer Kyowa| Lateral Acceleration, Deceleration | ±98.07 m/s² (±10 G) | ±1%                  |
| AMA-A                       |                   |                                   |                      |
| GPS Garmin GPS-18x          | Longitudinal Velocity | < 3 meters                      | 0.2 km/h             |

Figure 5. Instrument (left) and it’s location in the tested car (right).
3.5. Driving Robots
The driving robots can be installed in almost any vehicle and can deliver repeatable and accurate control. This tests used steering robots and pedal robots to control the test vehicle.

3.5.1 Steering Robots.
The steering wheel robots were used to control the steering wheel of test vehicle in severe-lane change and steady state tests. For both test procedures, the steer angle are significant to validate the vehicle. This equipment can control steering wheel up to a maximum angle of 360 degree at a velocity of 5 m/s.

![Figure 6. The steering wheel and pedal robots, which was selected for this testing.](image)

3.5.2. Pedal Robots.
The pedal robots included throttle and brake actuator as shown in figure 6. The throttle actuator has been used to control speed for all tests procedures. Furthermore, brake test procedure requires pedal force, which was provided by a brake actuator. This equipment can control a range of pedal forces.

4. Results and Discussion

4.1. braking test
In all braking tests results, the transmission is disengaged and engaged conditions as shown in figure 7. The maximum average braking deceleration occurred for new tires at 7.50 m/s² while transmission engaged. The lowest average braking deceleration for used tire (2013) was when transmission disengaged. In addition, the maximum value in engaged condition was higher than in disengaged condition. Therefore, brake deceleration relied on tires aging and transmission conditions. Furthermore, tires aging is a significant parameter for braking deceleration.
Figure 7. Time histories of braking deceleration at transmission engaged conditions (top) and time history of braking deceleration at transmission disengaged conditions (bottom).

4.2. steady state circular testing
From steady state circular testing, the condition of test with circular (8 m.) radius, new tires (2018) have the maximum lateral acceleration at 8.25 m/s², 33.49 km/h. The lowest lateral acceleration appeared with used tires (2013) during 6.8 m/s², 28.75 km/h. Therefore, lateral acceleration relied on vehicle speed and tire aging. Moreover, lateral acceleration decreases due to tire aging. Thus, it was a significant parameter for decreasing lateral acceleration under the same steer angle.

Figure 8. Vehicle speed for Lateral acceleration at constant radius.

4.3. Results of severe lane-change testing
Under the same condition of test with different velocity(40,50 km/h) and age of tires, it was discovered that the maximum yaw rate occurred on new tires (2018) at 50 km/h as shown in figure 9 (right). The lowest yaw rate appeared on used tires (2013) at 40 km/h. Therefore, yaw rate relied on vehicle speed and tire aging. Moreover, tire aging was significant parameters for decreasing yaw rate under the same velocity.
Figure 9. Time histories of maximum yaw rate at 40 km/h (left) and time history of maximum yaw rate at 50 km/h (right).

5. Conclusion
This study is present the procedure to measure the performance of tires. The tests performed on tires showed that different aging resulted in significantly different braking deceleration, lateral acceleration and yaw rate values. All the tests covered lateral force and longitudinal force.

In the all braking tests at 100km/h conditions with transmission engaged and disengaged, the results show approximately 4% decreasing in deceleration rate, that affected from engine deceleration. In addition, braking deceleration from used tires when compare with new tires is reduced approximately 2-3% in every age group and effect significantly to vehicle braking performance.

For the steady-state circular tests in fixed steer angle conditions, the lateral acceleration of new tires was almost linear. In case of used tires the characteristics of lateral acceleration change was strongly non-linear. This non-linearity points show poorer stability in the range of lateral acceleration. In addition, lateral acceleration at terminal speed in used tires was reduced approximately 5-7% in every age group. Therefore, the tests revealed that, compared with new tires, the majority of used tires showed a lower cornering performance of vehicle.

The results of tests prove that the differences in the manner of driving a car with tested tires are relatively significant, particularly in reference to maximum yaw rate in the path of severe lane-change manoeuvre. The test showed the maximum yaw rate for used tires were lower than new tires. In addition, maximum yaw rate from new tires to used tires was reduced approximately 2-9% in every age group. Thus, the tests revealed the majority of used tires showed a lower handling performance of vehicle when compared with new tires.

The result of new tires and used tire had the same trend for both longitudinal and lateral tire force. Therefore, this research fulfills all of the conditions of the real road driving to develop the tire testing model.

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