



The Effect of Tire Pressure Changes on Braking Efficiency and Necessity of Adjusting Tire Pressure Before Braking Test at Vehicle Technical Inspection Centers

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ABSTRACT

Braking test is one of the most important tests of a mechanized technical inspection line. In this study, the effect of tire pressure changes on the accuracy of the braking test results is investigated at technical inspection centers. This study is conducted in three stages. In the first step, the braking efficiency at different tire pressures is examined using a roller brake tester. In the second step, the tests at different pressures and velocities on the road are done. These tests are carried out in terms of stopping distance, to ensure the accuracy and reliability of the first step test results. The results of the first and second steps showed that the effect of tire pressure changes on the braking efficiency is significant. In the third step, the braking test results of a thousand vehicles that received technical inspection certificate are studied. Analysis of these results, considering the results of the first and second steps cleared that about 16% of vehicles that received technical inspection certificate have lower braking efficiency than the minimum acceptable efficiency. The obtained results specified the necessity of adjusting the pressure of tires before the braking test at vehicle technical inspection centers in Iran.

1. Introduction

Over 3400 people die on the world's roads every day and tens of millions of people are injured or disabled every year [1]. Road traffic injuries were the eighth cause of death in the world [2] and the third cause in Iran in 2016 [3]. Between 2006 and 2016, more than 208,000

people were killed in road traffic accidents in Iran [4]. In 2017 in Iran, the number of people who lost their lives in road traffic accidents grew by 1.7% year-on-year to 16,201. Also, the number of injured people rose by 0.9% to 335,995 [4]. Rapid motorization in low and middle-income countries- where the risk of road traffic crash is highest- and the growing the manufacture and use

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of vehicles taking place in these emerging economies means there is an urgent need for the minimum vehicle standards to be implemented by every country [5]. The safety of vehicles in two stages of production and after production is significant. Vehicle technical inspection centers play a fundamental role in the safety of vehicles in the years after production. The technical inspection certificate must be such that the owner of the vehicle at the time of receipt it be assured of the full safety of the vehicle; therefore, it is imperative that the technical inspection tests are carried out in perfect accuracy at vehicle technical inspection centers. A mechanized technical inspection line consists of several tests that braking test is one of the most important ones. Brakes are one of the essential components of vehicle safety, which play a unique role in reducing fatalities and financial losses. Brake system performance significantly affects safety, handling and vehicle dynamics [6]. The importance of braking efficiency increases when we know some drivers are slow in making decision during emergency. They also might be panic and not giving the sufficient force for braking to put the car to stop [7]. Other research has focused on the importance of vehicle brakes and related issues, some of which are mentioned [8, 9, 10, 11, 12, 13].

At a vehicle technical inspection center, the braking acceleration is determined using the roller brake tester. Braking acceleration is the rate of deceleration of the vehicle per unit time during braking. The braking acceleration is obtained by Newton's second law and from Equation 1 [14]:

$$F = ma \rightarrow a = F/m \quad (1)$$

Where a is the braking acceleration, F is the sum of the braking forces and m is the total mass of the vehicle. On the other hand, the braking acceleration is also calculated by the Equation 2 [14]:

$$a = (v^2 - v_0^2)/2d \quad (2)$$

Where a is the braking acceleration, v is the final velocity, v_0 is the initial velocity and d is the stopping distance. The stopping distance is the thinking distance (reaction time) plus the braking distance [15], but in this article, due to the driver's mental readiness to brake in a certain

place, the braking distance is considered the same as the stopping distance.

The braking efficiency is also obtained from Equation 3 [16, 17]:

$$E = F/mg \rightarrow E = a/g \quad (3)$$

Where E is the braking efficiency, a is the braking acceleration and g is the gravity acceleration.

From Equations 1, 2 and 3 we obtain the following results: A) The braking acceleration and stopping distance are inversely correlated. B) The braking efficiency and braking acceleration are directly related.

Based on on-road tests, tire pressure has a direct effect on the braking efficiency and stopping distance [18]. Dzmitry Savitsky et al. showed that a decrease in tire pressure improves braking in terms of stopping distance [19]. According to the results of experimental brake tests, the reduction of the tire pressure from 2.4 to 1.5 bar, reduced the stopping distance by 20% and increased the braking acceleration by 27% [20]. Ishann P. Mehta et al. reported braking distance of a vehicle decreases with decrease in inflation pressure of tires and rolling resistance increases by 38.3% when tire pressure is reduced by 62.5% [21]. In another study, with increasing tire pressure, the rolling resistance decreases and vice versa [22, 23]. Lower tire pressure increases tire and road contact surface and increases rolling resistance too [24]. Due to the internal damping of the tire material, the energy spent in deforming the tire material is not completely recovered when the material returns to its original shape. A force can represent this loss of energy on the tires called the rolling resistance [25]. Rolling resistance is one of the most important of the resistive loads against vehicle motion. It is a primary factor at low speed and hard pavements. When the nominal tire pressure is 29 psi, the pressure drop to 15 psi can increase the rolling resistance by the amount of 30%. Also, the rolling resistance decreases by 8% when the tire is inflated to 36 psi [26]. The present study is aimed to compare the results obtained from this paper with those from other researchers, and using the results obtained to increase the accuracy of the braking test at vehicle technical inspection centers.

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In this study, specific tests are used to examine the effect of tire pressure on the braking efficiency and stopping distance when applying the brake. These tests are designed into two groups; the first group included trials that are done for roller brake tester at Baran vehicle technical inspection center in Saveh, using different amounts of tire pressure. The second group consisted of tests that are done on the road at different velocities and different values of tire pressure.

In the present study, first, the method of doing tests is given; and then test results are offered. In the following, the technical test result documents of a thousand vehicles that received technical inspection certificate are studied, and a particular fact is obtained. Finally, considering this fact and the results of the roller brake and the road tests, solutions are proposed to increase the accuracy of the braking test at vehicle technical inspection centers.

2. Method

Tests related to the examination of the effect of tire pressure on the efficiency of braking and stopping distance when using the brake in two sections are performed. A roller brake tester was used to measure the braking efficiency. It should be noted that according to Equation 3, the braking acceleration and braking efficiency are directly related. This equation shows that increasing and decreasing each of them means increasing and decreasing the other. Road tests have also been used to measure stopping distances. According to Equation 2, the braking acceleration and stopping distance are inversely correlated, so by testing each of them, the status of the other parameter is determined; this means that the increased braking acceleration reduces the stopping distance and vice versa. On the other hand, when the stopping distance is reduced, it can be concluded that the braking acceleration has increased and vice versa. However, these results are acceptable if the same testing conditions and similar braking forces are applied. In the roller brake tester due to the constant speed of roller rotation, the variable factor was only the tire pressure. In the road tests to ensure the accuracy of the tests, in addition to the tire pressure, the vehicle velocity was also a

variable factor. After conducting the tests, the technical test result documents of a thousand vehicles that received technical inspection certificate are separately examined for the factors of braking efficiency and tire pressures. Finally, specific results are obtained.

2.1 On the Roller Brake Tester

For doing tests on the roller brake tester and determine braking efficiency, these instruments are used:

A sedan vehicle (made by Brilliance, 2016, with anti-lock brake system (ABS) and tires with 9 mm treads, net weight of 1240 kg, equipped with cruise control system and an electrical circuit to record the brake pedal course time) and a roller brake tester (made by Actia Muller, 2010) shown in Figure 1. One advanced feature in braking system of modern vehicles is ABS. Locking up of front and rear wheels can cause loss of vehicle stability and an increase in stopping distance. When a wheel lock up is detected, the braking control system reduces the pressure applied to the brake actuators and brings the wheel back to spinning [27].

Before doing tests, the health of the elements of the brake system, especially brake discs and pads, is examined by repairpersons in the official representative of the automotive company. They are important parts of a disc brake system through which the braking force is transferred to the rotor and the tires to decelerate and/or stop the car [28]. The calibration of the roller brake tester is examined by experts in the official representative of the corresponding company, too.



Figure 1: The tests on the roller brake tester at different pressures

The tests related to this section are designed in one day under load pressures of 2, 1.6, 1.3, and 1 bar, and for each pressure, they are repeated three times. In total, 12 tests are done by an interval of 30 minutes. The reason for doing tests three times for each pressure is to obtain the average of incorporated efficiency and to ensure the reliability of the test results. The interval of 30 minutes between tests is considered necessary to provide equal temperature conditions in the elements of the brake system. Talati & Jalalifar [29] stated that repeated long stops cause an increase in the temperature of the brake system as well as a decrease in the functioning of the system. An increase in the internal temperature of tires leads to a reduction in the rolling resistance coefficient. After that, there will be a decrease in the efficiency of the brake system [30]. An electrical circuit is used to record the brake pedal course time to ensure the braking rate. In fact, this is the time when the brake circuit pressure reaches from lowest to maximum. This electrical circuit is shown schematically in Figure 2.

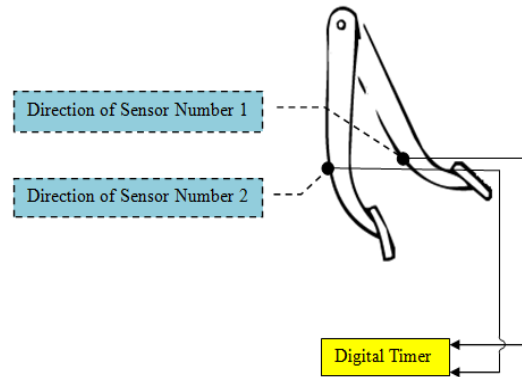


Figure 2: The electrical circuit to record the brake pedal course time on the roller brake tester

The circuit uses two high-speed transistor optical sensors and a digital timer. With the first movement of the brake pedal, Sensor 1 sends a pulse to the digital timer and activates it. Sensor 2 also announces the end of the brake course with another pulse and stops the digital timer. The digital timer works with one millisecond accuracy and a DC power supply. Therefore, the brake pedal course time is measured and recorded in each brake test.

The results of tests for the roller brake tester are given in Table 1. The standard deviation values are also shown in the table.

Table 1: Braking efficiency on the roller brake tester at different pressures

Tire pressure, [bar]	Average brake pedal course time, [s]	Average efficiency, [%]
	Standard deviation, [σ]	Standard deviation, [σ]
2	0.340	66.3
	0.006	0.84
1.6	0.349	70.6
	0.009	0.84
1.3	0.353	73.6

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	0.006	0.23
	0.350	75.5
1	0.009	0.4

2.2. On the Road

The recent worldwide intensification of the traffic regulation forces car makers to announce the braking distance of their new models [31]. The braking distance indicates the total distance traveled by a vehicle starting from braking at the velocity of 100 km/h to stop, and its estimation has been traditionally carried out experimentally [31].

In this study, road tests are done one day after the tests for the roller brake tester. To do these tests and to determine the stopping distance when using the brake, the same vehicle is examined in roller brake tests. The road had appropriate asphalt with no bumps. Road tests are also done in one day under load pressures of 2, 1.6, 1.3, and 1 bar; and at initial vehicle velocities of 100 km/h and 90 km/h. In the tests, all conditions except the tire pressures and velocities were the same.

In the present study, the stopping distance is investigated at two velocities. The stopping distance test is not common at velocities other than 100 km/h, but in this study also carried out at a velocity of 90 km/h. The reasons for this were to compare the stopping distances and to ensure the results of the test results at a velocity of 100 km/h. For each velocity and pressure, the tests are repeated three times. In total, 24 tests with an interval of 30 minutes are done (see Figure 3). The reason for doing tests three times for each pressure and velocity is to obtain the average of incorporated stopping distance and to ensure the reliability of the test results. The interval of 30 minutes between tests is considered necessary to provide equal temperature conditions in the elements of the brake system.



Figure 3: The tests on the road at different pressures and velocities

Positive or negative acceleration of the vehicle at the time of starting the braking, respectively, increases and reduces the stopping distance. Due to ensure the vehicle's acceleration being zero when using the brake, the vehicle goes a distance of 300 meters before the braking place at a constant velocity. Constant velocity is provided using the cruise control system. Braking is done in the shortest period in a way that the brake pedal is pushed entirely. The force exerted on the brake pedal was maintained until the vehicle stopped completely. In these tests also, an electrical circuit is used to record the brake pedal course time to ensure the braking rate. In fact, this is the time when the brake circuit pressure reaches from lowest to maximum. This electrical circuit is shown schematically in Figure 4.

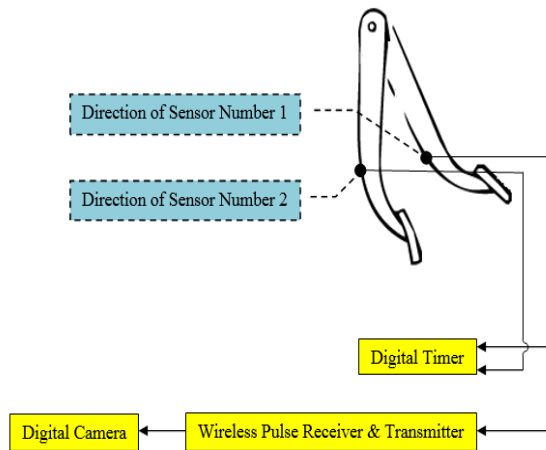


Figure 4: The electrical circuit to record the brake pedal course time on the road

The circuit uses two high-speed transistor optical sensors, a digital timer, a wireless pulse receiver & transmitter block and a digital camera. With the first movement of the brake pedal, sensor 1 simultaneously sends one pulse to the digital timer (the digital timer works with one millisecond accuracy and a DC power supply) and another pulse to the wireless pulse receiver & transmitter block. The mentioned block also sends a pulse to the camera installed near the braking place and outside the vehicle to record the exact position of the vehicle at the start of the braking by taking a photo. As soon as the brake pedal reaches the end of its course, sensor 2 sends a pulse to the digital timer and stops it. Therefore, the time of the brake pedal course is registered by the digital timer and the exact position of the vehicle at the start of the braking by the digital camera. After each test, the stopping distance by the meter was measured manually. The results of tests on the road are shown in Table 2. The standard deviation values are also shown in the table.

Table 2: Stopping distance at velocities of 100 and 90 km/h at different pressures

Tire pressure, [bar]	Velocity, [km/h]	Average brake pedal course time, [s]	Average stopping distance, [m]
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		Standard deviation, [σ]	Standard deviation, [σ]
2	100	0.359	49.2
		0.003	0.78
	90	0.359	39.1
		0.009	1.1
1.6	100	0.349	47.8
		0.018	0.87
	90	0.361	38.3
		0.005	0.81
1.3	100	0.362	44
		0.004	1.39
	90	0.350	35.6
		0.007	0.65
1	100	0.352	41.8
		0.016	0.49
	90	0.358	32
		0.012	0.49

2.3. Technical Test Result Documents at the Technical Inspection Center

At this stage, the technical test result documents of a thousand vehicles that received technical inspection certificate are studied. These vehicles were part of the process of this study. After performing technical inspection tests on these vehicles, including the braking test, the tire pressures of each vehicle is measured manually and recorded in the respective results sheet. Then each of these sheets is separately examined for the factors of braking efficiency and tire pressures. According to these factors, the results obtained from the roller brake tester in Table 1 and the minimum efficiency required for acceptance in the braking test at the vehicle technical inspection centers in Iran (at least 50% In accordance with the guidelines of Article 3 of the regulations on the procedure for carrying out

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technical inspection and issuing technical inspection certificate of the vehicle) [32], the important result is obtained. This result showed that the method of braking test in Iran's technical inspection centers should be reviewed.

3. Results

1. Braking efficiency on the roller brake tester, with a decrease in tire pressure from 2 to 1 bar, increased by 12 %.
2. Stopping distance when using the brake on the road, at a velocity of 100 km/h, with a decrease in tire pressure from 2 to 1 bar, decreased by 15 %.
3. Stopping distance when using the brake on the road, at a velocity of 90 km/h, with a decrease in tire pressure from 2 to 1 bar, decreased by 18 %.

The result obtained from studying the technical test result documents of a thousand of vehicles that received technical inspection certificate, according to their tire pressures during the braking test and the effect of tire pressures on the braking efficiency is summarized as follow:

4. About 16% of these vehicles had poor brakes. These vehicles did not qualify for technical inspection certificate, but due to the lower tire pressures than the standard pressures, they successfully passed the braking test and received the technical inspection certificate.

4. Discussion

In Iran, after the production of the vehicle and at the time of its operation, the only site that is able to inspect the vehicle in a mechanized and scientific manner is the technical inspection center. Technical inspection centers with the presence of world-class equipment and trained experts play a major role in restoring or confirming the safety of vehicles. Due to the presence of low-quality vehicles, low-skilled repairers and low-quality spare parts in the country, the role of the technical inspection centers becomes more intense. These centers, which are continuously inspected by government legal bodies, have a special position in traffic

safety. The results of the tests performed in these centers are very important and valuable. Therefore, it is essential that the tests are carried out in standard conditions to ensure the accuracy of the results. The perfect performance of the technical inspection centers is also effective on the technical progress of the repairers. Correct identification of the defects and the provision of correct solutions for repair by the experts of technical inspection centers can provide a clear direction to the repairers. The solutions presented and their accuracy depends on the accuracy of the results obtained from the tests. Next, the experts of the centers analyze the results.

In an aspect of vehicle accident prevention, the braking performance of vehicles has been considered as a critical issue [33]. Braking test is one of the most important tests defined for a mechanized technical inspection line. Braking test is carried out in Iran's technical inspection centers regardless of the tire pressures; while according to various researchers' findings and the results obtained in this study, tire pressure changes cause unrealistic braking efficiency at vehicle technical inspection centers. The results obtained from the tests in this study are compared with the results obtained by other scholars. The obtained results were insignificant congruence with together. The results of tests for the roller brake tester showed that the reduction in tire pressures from 2 to 1.6, from 2 to 1.3 and from 2 to 1 bar increased the braking efficiency by 6, 10 and 12%, respectively. The results of the road tests confirmed the roller brake tester results; this means that at a velocity of 100 km/h, with a reduction in tire pressures from 2 to 1.6, from 2 to 1.3 and from 2 to 1 bar, the stopping distance is reduced by 3, 11 and 15%, respectively. At 90 km/h these values were 2, 9 and 18%, respectively. Increasing the braking efficiency reduced the stopping distance.

When the tire pressure is low, the roller brake tester records a higher efficiency than the real efficiency of the vehicle. So, this vehicle passes the braking test successfully at a technical inspection center. This vehicle and similar vehicles, due to the poor performance of the

brakes, can increase road traffic accidents. Low tire pressures can be intentional or unintentional, but anyway, it shows the braking efficiency unrealistic. In this situation, the expert of the technical inspection center is mistaken and cannot provide an accurate analysis of the results. This is contradictory to the main mission of the technical inspection centers because the results of the braking test are false and unreliable. For example, a vehicle with a standard tire pressure of 2 bar has a tire pressure of 1.3 bar at the time of the braking test. The vehicle records a 54% efficiency in the braking test and receives technical inspection certificate. Obviously, due to the low tire pressures, the recorded efficiency is not real. According to Table 1, the reduction of tire pressure from 2 to 1.3 bar increases the braking efficiency by 10%. If this trend is true for a given vehicle in the example, the real braking efficiency of this vehicle will be 49%. With a braking efficiency of 49%, this vehicle has poor brakes. Therefore, in order to receive technical inspection certificate, the performance of the brakes should be improved.

In the European Union, 50% of all vehicles are driven on underinflated tires [34]. Given the statistics for vehicles inside Iran, the results of the braking test of this category of vehicles are not valid at the technical inspection centers because the real braking efficiency is different from the efficiency recorded by the roller brake tester. Of course, the difference may not be so much that the car will fail in the braking test, but it certainly will deceive the expert of the technical examination center. The expert cannot provide an accurate analysis of the brake performance. In addition, driving with low-pressure tires for long periods of time has negative effects on fuel consumption, tire wear and driving comfort [35].

According to the explanations given, the results of the tests carried out in this study and the results of other studies, it seems that adjusting the tire pressure at the technical inspection centers is very necessary to ensure the braking test results. Surely this should be done by the experts of these centers. Tire Pressure Monitoring System (TPMS) can significantly help experts in this task (see Figure 5). A TPMS is a driver-assist system that warns the driver when the tire pressure is

below or above the prescribed limits [36]. Using this system, drivers and experts at the technical inspection centers can easily understand the low tire pressures. For example, all new passenger vehicles weighing under 10,000 pounds sold in the U.S. as of September 1, 2007, be equipped with a TPMS [37]. In 2009 the EU parliament mandated ECE-R 64, a regulation requiring all new vehicle types to be equipped with a TPMS starting November 2012 and all new vehicles to be registered from November 2014 [38]. In Iran, of course, most vehicles that go to the technical inspection centers are not equipped with a TPMS. Therefore, there is no other way than to manually control and adjust the tire pressure of these cars for the experts at these centers.



Figure 5: Tire Pressure Monitoring System (TPMS)

5. Conclusions

Using the results obtained can increase the safety of vehicles and prevent further road traffic accidents. Assuming that all vehicles in the country receive technical inspection certificate within a specified period, about 16% of them have poor brakes. Due to solve this problem and increase the accuracy of the braking test results at the technical inspection centers, the following suggestions are presented:

- 1- Equipping all the vehicles manufactured or assembled by Iran or imported vehicles with a TPMS.
- 2- Manual tire pressure gauge checks must be made compulsorily before carrying out the braking test at the technical inspection centers, if vehicles are not equipped with a TPMS.

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The focus of this paper is on experimental evaluation and testing. A tire physical model which takes into account the effect of tire pressure on the longitudinal stiffness, will be studied in future researches to optimize a variable tire pressure system. Tire pressure changes are also effective on the results of the shock absorber test. This effect is being examined now by the authors of this study for next publications.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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