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Experimental Study into the Torsional Friction between AGV Wheel and Various Floors

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Abstract. This paper presents an outcome of the experimental study into torsional friction between small sized wheels, intended for AGV, while being in contact in three different floors. The dedicated test stand was developed, which allowed testing a wheel while turning at various velocities. Each wheel was loaded via a pneumatic actuator. Turning was performed by parallel mechanism by using a turntable powered by a stepper motor. Nine different wheels were tested at three different turning angular velocities. Linear characteristics were obtained between torque required to turn and normal load, which allowed estimation of the coefficients of torsional friction for each wheel. A clear material hysteresis while turning and returning was observed for most cases. It was found that hardness and wheel geometry play important roles in the torsional behavior under load.

Introduction

The aim of this work is to study experimentally torsional behavior between AGV (Automated Guided Vehicle) wheel and typical floors. Different driving methods exist for four-wheeled vehicles: Ackermann steering, differential driving method, steering by using omnidirectional wheels or by skidding. Each of these approaches have certain advantages and disadvantages which determine their applicability in certain work conditions. They also implicate the dynamics of the vehicle during straight drive or turning, including frictional behavior. The subject of our study are commercially available wheels which are installed on a vehicle with the Ackermann steering system. In this case, apart from rolling friction, torsional friction occurs which can change with steering angular velocity.

Friction is one of the fundamental phenomena existing in nature. It significantly affects the operation of a mechanical system. The friction can be undesirable or desirable as it depends on the character and purpose of the design or process. An important dependence of contacting bodies is a relation of friction force as a function of the relative speed during contact [1]. In the basic engineering calculation it can be assumed that this relationship is constant. Stribeck proved that as the relative velocity of the bodies increases, the friction force decreases. This applies to the range of low slip velocities and is especially important when initiating stick-slip movements. Dry friction has discontinuities in its description, which leads to the solution being the result of approximation [1, 2, 3]. Interaction friction models, such as for example mass, spring and dashpot lead to the appearance of hysteresis friction model. Excessive friction contributes to wasting energy converted, finally, into financial losses. On the other hand, insufficient friction is the cause of many accidents. In production processes, the friction is vital for grinding and polishing [4].

In the literature, the common problem is the estimation of the car tire friction coefficient. Most often these studies concern lateral movement, longitudinal movement or their combination.

Each of these directions is associated with a unique value of coefficient of friction [5]. The lateral friction coefficient of a tire is the subject of multiple scientific papers. The main reason for this is unfavorable lateral tire deflection. The basic ground in the tests is usually asphalt [6]. Aligning moment occurring in these tests is not a torsional moment causing torsion friction. Despite that, its dependence in the displacement function occurs in the form of hysteresis [7].

Torsional contact is one of the main problems regarding the contact of bodies. The model assuming perfect smoothness of the contacting bodies leads to simplifications. In this model, two zones exist: slip area and adhesion area [2, 8]. Torsional moment is dependent on rolling speed. For maneuvers at a low speed, this torque takes maximal values. As the rolling speed increases, the steering torque decreases. It is also observed that the hysteresis loop is wider at lower speeds. The influence of the speed on the torque value was simulated using the finite element model. The simulation results were validated for a speed of 10 km/h by the vehicle steering torque tests [9]. In passenger vehicles, simulation procedures are used to show steering behavior during a turn. There are definitely more factors involved in this analysis than in the case of the model in which the torsional moment causes direct motion. The moment in the steering wheel occurs in the form of hysteresis [10]. The analyzes were devoted to road tires. A comparison of different types of wheels has not been carried out [5, 6, 7, 8, 9].

The torsional friction is a key factor in torsional fretting. The moment occurring in that process in the function of the steering angle is presented in the form of the aforementioned hysteresis. Hysteresis loop occurs for both metals and plastics [11, 12]. These studies have been extended showing the influence of the atmosphere on the hysteresis shape [13]. Experiments were conducted in order to check the influence of the number of rotation cycles on the change of the shape of the torque curve as a function of the angle of rotation. In this study, the influence of the pressure force and angular displacement amplitude on the form of hysteresis was also checked. It has been shown that the shape of the curve depends on the angle of torsion. For contacting materials PTFE, steel and normal load equal 123N hysteresis was rectangular for largest torsional angle(15° and 30°). For smaller steering angle(0,5° and 1°) shapes of curves were quasiparallelogrammatical. As the steering angle increases, the maximum torsional friction torque decreases until the angle reaches 5°. It has been shown that the increase of the normal force does not significantly affect the character of the moment curves, only the increase in amplitude. This was done for a narrow range of normal loads and only one pair of contact materials. For other data, parameter changes may have a different effect on the hysteresis shape [8]. Hysteresis also occurs in the frictional torsion dampers as dependence of the friction torque as a function of the torsion angle [14, 15]. On the basis of studies on torsional friction between the materials of an artificial knee joints, it was shown that material wear decreases with the increase in the steering angle amplitude, but increases with the pressure force. The torsional friction was simulated in ANSYS for rubber wheel using the finite element model. The amplitude of the rotation angle was ±2° [16].

Materials and methods

In the study, we used nine commercially available wheels of the same outside diameter (160 mm) and mounting hole (Fig. 1).. They are dedicated for internal transportation systems. The maximum load on the wheels from weight is between 250 and 400 kg. Material specifications of the investigated items are shown in Table 1. Specimen differ mostly in tread and tire material and resulting Shore hardness that is declared by the manufacturer. The core of wheel 6 was made of polyamide, the others were made of casted aluminum. The tire of wheel 7 is barrel-shaped which, according to the producer, is supposed to improve the torsional performance.

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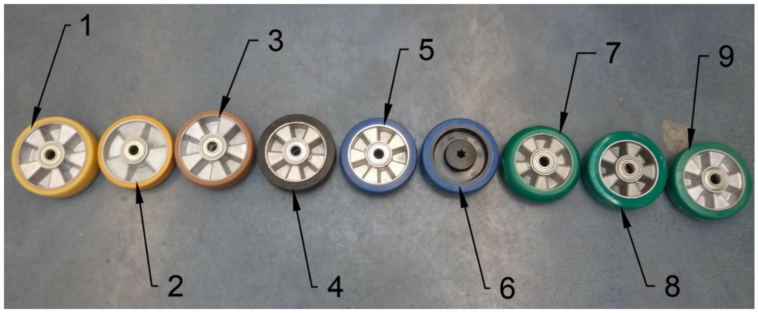

Fig. 1. Overview of the investigated wheels

In order to study the torsional phenomena, a dedicated test stand was developed (Fig. 2), which allowed testing a wheel while turning at various velocities. Each wheel was loaded normally via pneumatic actuator. Four load values were used: 1, 2, 3 and 4 kN. In order to maintain constant pressure and, thus, force, pressure was measured and stabilized through electrically powered pressure valve that was closed-loop controlled. Turning was performed by parallel mechanism and using turntable powered by stepper motor. All wheels were tested at three different turning angular velocities 10, 20 and 25 degrees per second. The material, in contact were concrete and two resin type floors (white – harder and blue – softer).

The torque required to turn the wheel under load was measured through a force meter fitted in the turning link. The torque was calculated taking into account the angular position. The data was collected by HBM DAQ unit connected to PC with Catman software installed. We have collected both the load force and torque. The turn angle was collected from a stepper motor controller.

Table. 1. Parameters of analyzed wheels.

Wheel number	Core material	Tread and tire material	Tread and tire hardness [° Shore A]
1	Aluminium	Extrathane® Polyurethane	92
2	Aluminium	TR® Polyurethane	95
3	Aluminium	Besthane® Polyurethane	92
4	Aluminium	EasyRoll® Rubber	65
5	Aluminium	Besthane® Soft Polyurethane	75
6	Polyamide	Besthane® Soft Polyurethane	75
7	Aluminium	TR-ROLL® Polyurethane	75
8	Aluminium	TR-ROLL® Polyurethane	75
9	Aluminium	Softhane® Polyurethane	75

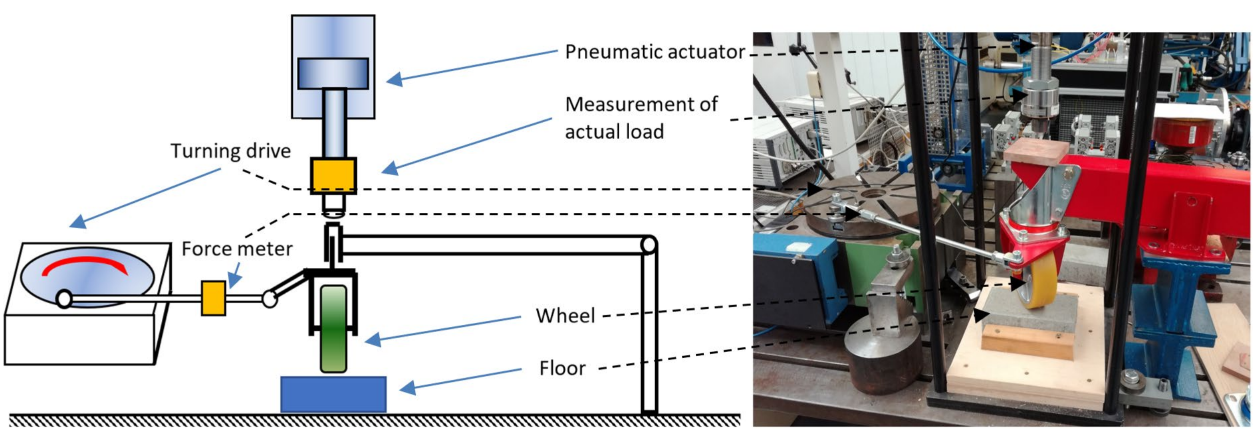

Fig. 2. The schematic and the actual view of the test stand

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Results and discussion

The torque (torsional moment) versus turn angle relation took the form of hysteresis, which varied in shape depending on the wheel, floor and testing conditions. For each measurement we analyzed the four characteristic parameters: positive and negative remanence as well as positive and negative coercivity (Fig. 3).

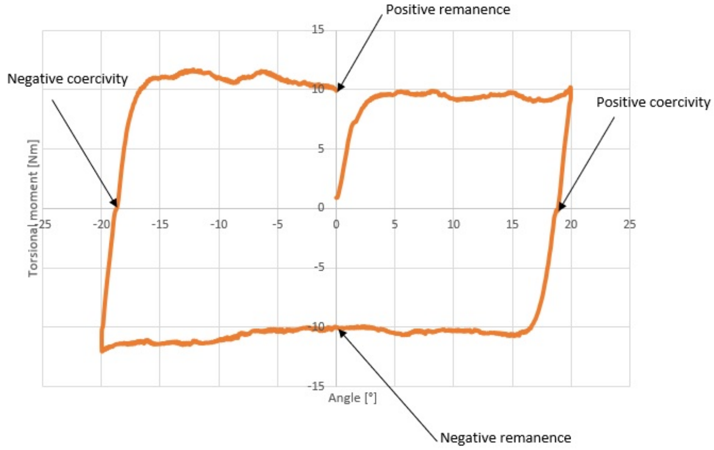

Fig. 3. Registered relation between torque and angle and hysteresis parameters.

We noticed that the shape of the hysteresis is mostly asymmetric and there are differences between positive and negative values of corresponding parameters. Those differences generally increase with the load, which is clearly evident for rubber tires (specimen 4) where the variations took the greatest values. The lowest differences in coercivity were observed for harder material (specimen 1-3). For the remanence no clear similar tendency could be noticed. We also found that the turning angular velocity (within 10-25 deg/s range) does not significantly influence the asymmetry of hysteresis. The results of mean differences between positive and negative coercivity as a function of load for all nine wheels while in contact with hard resin floor are shown in Figure 4. We observed no buckling of the connecting rod (calculated force in the rod was below critical force), which could be a potential reason of hysteresis asymmetry.

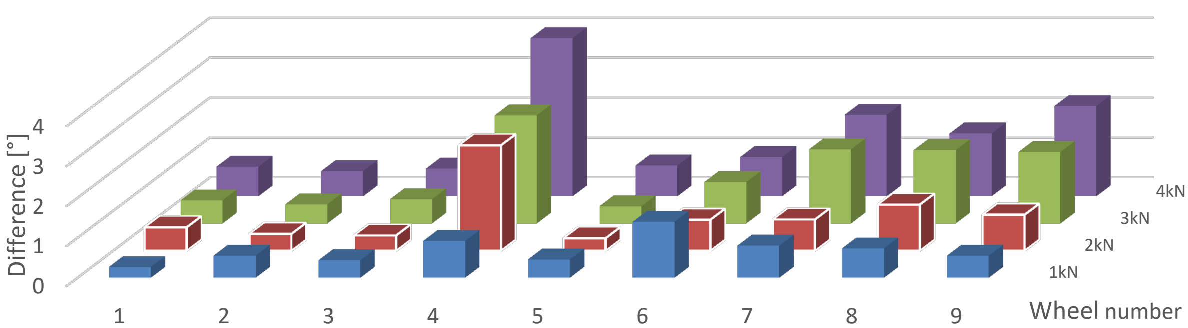

Fig. 4. Differences between positive and negative coercivity for all tested wheels

Basing on the obtained data, we determined characteristics between the torque required to turn and normal load, which allowed estimating coefficients of torsional friction for each wheel. We received a satisfactory linearity between load and torque (R^2>0.9 for linear regression). The characteristics for all measured wheels and floors are shown in Figure 5. We noticed that the highest values of torsional friction coefficient were measured for concrete paving floor. For that floor the wheel type does not influence the friction coefficient significantly when compared with other resin floors. Generally, greater values were observed for return than turn. In all cases, the rubber wheel showed the highest values of torsional friction coefficient.

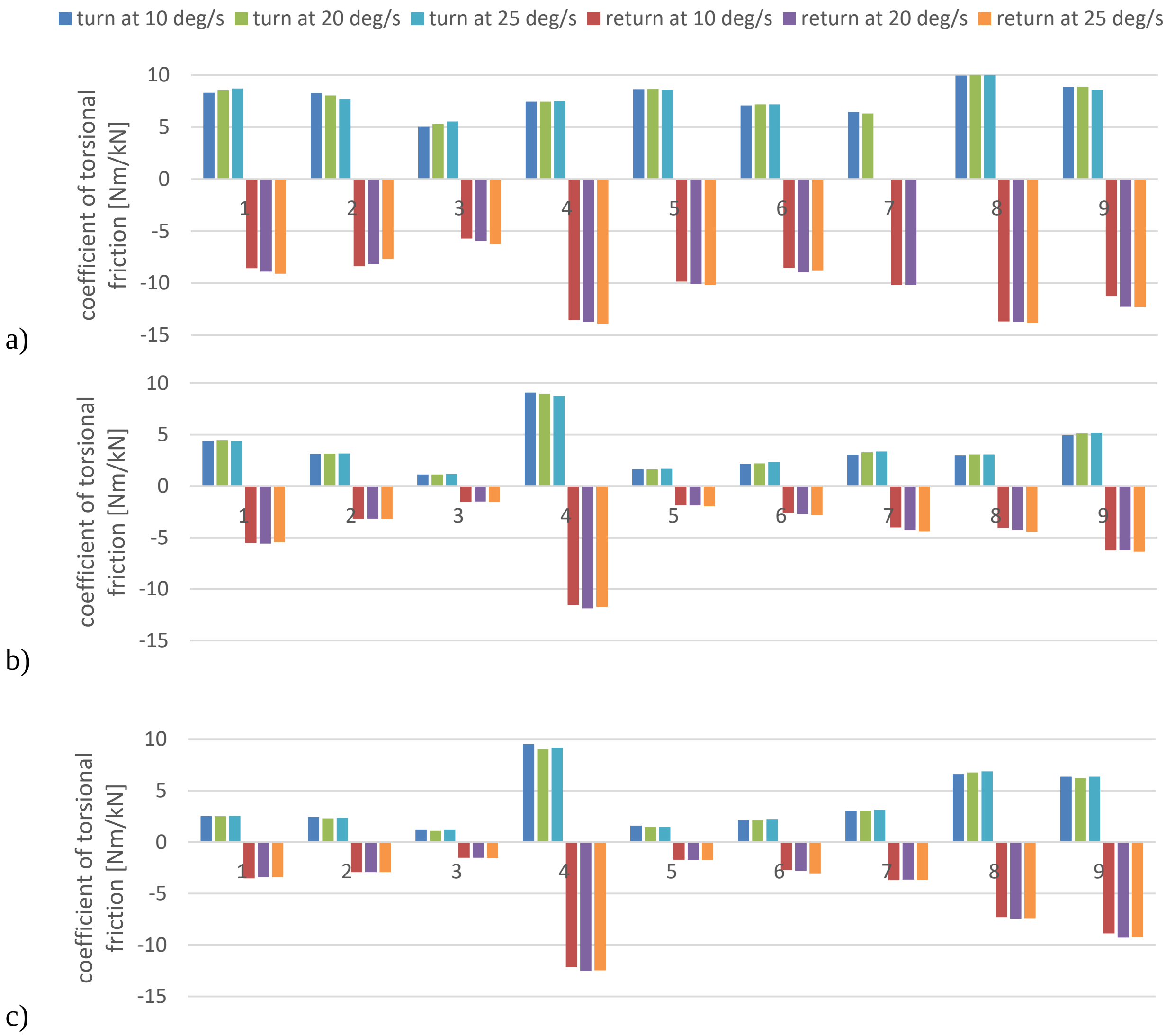

Fig. 5. Coefficient of torsional friction for all tested scenarios: a) concrete paving, b) hard resin floor, c) soft resin floor

Summary

Wheel shape and hardness play important role in torsional behavior. We noticed that hardness alone does not correlate strongly with coefficient of friction (R^2<0.5 utmost). The lowest torsional friction was achieved for hard material of tread and tire. The barrel shape wheels performed better when turning as compared to the wheels of the same material but flat tread. The rubber wheel required the most torque to turn in all tested conditions. The friction was also dependent strongly on the contacting material of the floor.

The estimation of the exact coefficient of friction is an important issue in the design of turning mechanism of an AGV. It determines the power of the drive, gearbox, battery size and electric current consumption. The torsional coefficient of friction can be difficult to estimate through simulation; therefore, a method for measuring the values in specific work condition might be a credible approach.

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