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RUNNING SAFETY ON THE CONTAMINATED TRAVELLED SURFACES

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Abstract

The target of this paper was to approach the safety of the both vehicle drivers and the travelling public on winter or rain with debris conditions of runways. This is why a correct estimation of the friction parameters and measurement services must be carefully approach. The theoretical aspects presented on the paper intended to cover elementary mechanics, dynamic influences on friction by contaminants, variability of friction measures, friction evaluation and confidence. The results presented are intended to serve as a guide for the researches, tire-surface measurement method designers, equipment manufacturers and operators in the field of measuring braking friction by public service regulations, vehicles drivers and other users of runway friction information.

Keywords: *running safety, tire-surface, contaminant, vehicle, braking slip friction.*

1. INTRODUCTION

The capability of the runway to interact with the vehicle wheels to provide a sufficient directional control below minimum air speed and sufficient wheel braking effect for accelerate-stop manoeuvres is critical for safe operations. However, the quality of the friction measurements has been questioned for uniformity in reported friction values for the same runway conditions and relevance to predicting vehicles braking performance. All sectors of the vehicles transport recognize the need for consistent and reliable information about the runway operation characteristics, including frictional properties. Driving regulations of vehicles manufactures and others have raised a question as to whether current friction measurement practices truly contribute to overall safety for ground operations [1-2].

Vehicles drivers that use contaminated travelled surfaces continue to demand accurate friction measurements as indispensable information for their work. Vehicle wheels braking on bare pavement, dry or wet, has been approached regarding to slip friction. From this point, slip friction will be used in this paper to clearly distinguish braking friction with tires from classical static friction. Travel speed, degree of braking tire type and surface texture are established parameters influencing the braking slip friction. Hydroplaning is an example of a well researched phenomenon on wet pavement under summer conditions. The phenomenon of hydroplaning, whereby a tire losses contact with the rigid ground and results in loss of ground control forces for a vehicle, has caused many accidents, some of which have resulted in the loss of human lives [3-5].

Taken into account al of these aspects the paper presents some theoretical results concerning both the friction parameters and measurement of travelled surfaces in the sense to increase the safety of both the vehicles drivers and the travelling public.

2. THE NATURE OF BRAKING SLIP FRICTION FORCES OF THE VEHICLE WHEELS

The mechanism of braking slip friction of the vehicle wheels can be regarded, to a great extent, as a composition of three phenomena (Fig. 1): adhesion, hysteresis and shear (wear, tear).

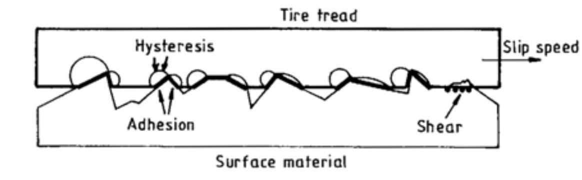

Fig. 1: *View of the wheel tire-surface interface.*

Generally, adhesion is related to micro texture whereas hysteresis is mainly related to macro-texture [6]. For wet pavements, adhesion drops off with speed increase while hysteresis increases with speed, so that above 90-100 km/h, the macro- texture has been found to account for over 90 percent of the friction. In the case of friction during snow, ice or rain, the shear strength of the contaminant is the limiting factor.

The braking slip friction force

$$F_B = F_A + F_H + F_S, \quad (1)$$

where: F_A - adhesion force, proportional to the real area of adhesion between tire and surface asperities; F_H - hysteresis force, generated within the deflecting and viscous-elastic tire tread material and being defined as a function of wheel speed; F_S - shear force, proportional to the area of the shear developed.

If the adhesion and hysteresis parts diminish relative to the shear in a given friction process, the braking slip friction approaches a measure of shear strength of the surface material as a function of the normal stress (contact pressure).

When braking a vehicle to stop from normal speed on a travelled surface, the braking slip friction force F_B generated in the tire-surface interaction is equal with decelerating force F_D acting on the vehicle mass:

$$F_B = F_D,. \quad (2)$$

The braking slip friction coefficient μ_B can be determined from the Newton's law:

$$\mu_B.F_W = F_W.a/g, \quad (3)$$

and

$$\mu_B = a/g, \quad (4)$$

where: F_W - normal force due to the vehicle weight; a - deceleration; g - gravitational acceleration.

This estimation is used to determine the average friction coefficient by measuring the deceleration of the vehicle. For higher speeds and a required accuracy, for the braking evaluation more resistive terms must taking into account: aerodynamic resistance, longitudinal slope of the surface, displacement drag from liquid, fluid or plastic materials, hydroplaning effects, brake efficiencies. These effects must be assessed and used to a correct measured value to determine a braking slip friction coefficient nearer to the real one [7].

3. MECHANICS OF THE WHEEL TIRE-TRAVELLED SURFACE INTERACTIONS

3.1 Rolling resistance force

To approach this aspect, in Fig. 2 are used the following notations: F_W - normal force due to the vehicle weight; F_G - resultant normal force due to an uneven normal distribution as result of a small tire longitudinal slip force; F_R - reaction force to the slip movement; F_M – rolling resistance force; ω - rotational speed of the tire in free-rolling mode; a - eccentricity of the resultant normal force; r - tire radius.

The sum of the moments on the wheel axis in a steady-state equilibrium is given by:

$$F_G.a - F_R.r = 0. \quad (5)$$

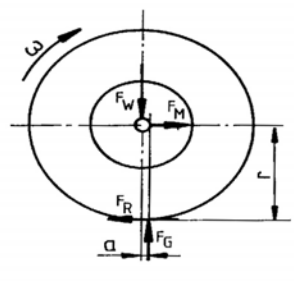

Fig. 2: *Rolling resistance force on a free-rolling tire.*

If the equality $F_G = F_W$ is assumed from the summation of the horizontal forces of the wheel in a steady-state equilibrium, a force-measurement device can measure the tire-rolling resistance force F_M if the design allows the applied brake moment to be uncoupled.

The friction coefficient, relative to the tire longitudinal slip force,

$$\mu_R = F_R / F_W = a/r. \quad (6)$$

3.2 Braking force

A constant applied braking force moment M_B works opposite to the rotation of the wheel (Fig. 3) and creates a slip resistive force F_B in the tire-surface contact area.

The sum of the moments on the wheel axis in a steady-state equilibrium is given by:

$$M_B - F_B.r - F_R.r + F_G.a = 0. \quad (7)$$

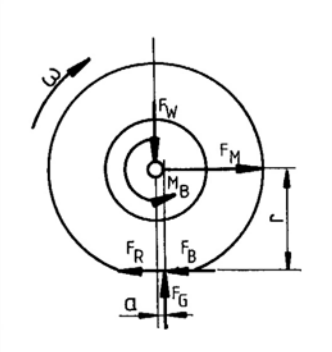

Fig: 3: *Forces and moments on a constant braked wheel on a dry rigid surface.*

Considering Eq. (5), a torque-measurement device can measure the reaction of the applied brake moment

$$M_B = F_B.r. \quad (8)$$

The measured horizontal force of the wheel in a steady-state equilibrium

$$F_M = F_B + F_R. \quad (9)$$

A force-measurement device can measure both the braking force and tire-rolling resistance force.

3.3 Contaminant drag force

When there is a contaminant on the travelled surface, the tire has to displace it to maintain a permanent contact with the ground (Fig. 4). The displacement causes a resistance to the wheel movement that acts in opposition to the direction of travel and in a parallel plane with the ground surface (it is presumed that the drag force acts in the centre of the normal frontal area of tire-fluid contact plane A_D).

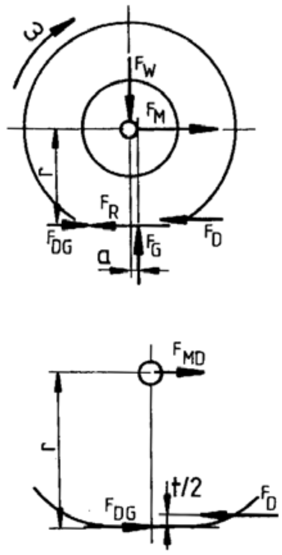

Fig. 4: *Drag forces acting on a free-rolling tire due to the fluid contaminant displacement.*

The drag force

$$F_D = (1/2) \cdot C_D \cdot \rho \cdot A_D \cdot v^2, \quad (10)$$

where: C_D - drag experimental coefficient; ρ - mass density of the fluid contaminant material; v - travel speed.

The wheel is supported by both the ground (force F_{DG}) and the suspension at the wheel spin axis (force F_{MD}) that must balance the drag force F_D.

The sum of the moments on the wheel axis in the horizontal drag subsystem is given by:

$$F_{DG} \cdot r - F_D \left(r - \frac{t}{2} \right) = 0. \quad (11)$$

The sum of the horizontal forces in the same subsystem is given by:

$$F_{MD} + F_{DG} - F_D = 0. \quad (12)$$

Substituting F_{DG} from Eq. (11) the measured drag force component

$$F_{MD} = \frac{t}{2r} \cdot F_D . \quad (13)$$

The sum of the horizontal forces of the complete free body is given by:

$$F_M + F_{DG} - F_R - F_D = 0. \quad (14)$$

Substituting F_{DG} from Eq. (11) the measured horizontal force of the wheel in a steady-state equilibrium

$$F_M = F_R + F_D \frac{t}{2r} . \quad (15)$$

A force-measurement device can measure both the tire-rolling resistance force and a fraction of the drag force.

3.4 Combined forces on the wheel

In the case of a simultaneously action of the tire-rolling resistance force, braking force and contaminant drag force (Fig. 5), the measured horizontal force of the wheel in a steady-state equilibrium

$$F_M = F_B + F_R + F_D \frac{t}{2r} . \quad (16)$$

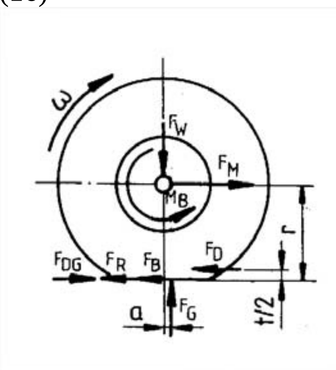

Fig. 5: *Combined rolling resistance, drag and brake forces.*

A force-measurement device can measure thus the tire-rolling resistance force, the braking force and a fraction of the drag force.

The sum of the moments on the wheel axis is given by:

$$M_B + F_{DG} \cdot r - F_D \left(r - \frac{t}{2} \right) + F_G \cdot a - F_R \cdot r - F_B \cdot r = 0. \quad (17)$$

Considering Eq. (5) and (11), a torque-measurement device can measure the reaction of the applied brake moment

$$M_B = F_B.r. \quad (18)$$

The friction coefficient, relative to the braking slip force

$$\mu_B = F_B / F_W = M_B /(r.F_W). \quad (19)$$

3.4.1 Friction forces from contaminant dynamic planning

During vehicle movement, the tires ride on the trapped fluid contaminant, which acts like a lubricant. The fluid contaminant gets trapped because there is insufficient time for the fluid to flow out of the footprint area. Moreover, the surface and tire tread may not have sufficient grooves or voids to allow the fluid to fill into these spaces, and thus escape readily from the tire footprint area. As the trapped fluid enters the leading edge of the contact area between tire and surface it gives rise to a fluid lift force acting to separate the tore from the base surface. When the fluid penetration covers all of the contact area with the ground, the tire-surface friction becomes approximately zero. The travel speed in this instance is called the critical hydroplaning speed when the fluid is water.

A tire friction mechanism with fluid planning and no brake applied is presented in Fig. 6.

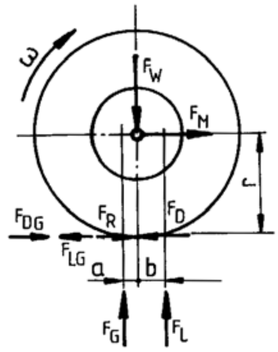

Fig. 6: *Free-rolling wheel with lift and drag.*

The reaction force from the ground has two components: F_G (the ground reaction force from the base surface still in contact with the tire) and F_L (the resultant dynamic fluid lift force from the area of interspersed fluid). The attack line of the force F_G is shifted back in the contact length distance *a* from the vertical line through the wheel axis. The fluid lift force F_L has an attack line at a distance *b* from the vertical line through the wheel axis and, also, an horizontal reaction force F_{LG} acting in the tire-surface area. The sum of F_R and F_{LG} constitutes a resultant rolling resistance force.

The fluid lift force F_L sustains no shear forces in its contact area with the tire and, therefore, no slip to support tire-rolling resistance in this area and at full planning it acts vertically through the wheel axis and the force F_G reduces to zero.

The sum of surface reaction forces is equal to the static weight carried by the wheel:

$$F_W = F_G + F_L. \tag{20}$$

A torque-measurement device measures zero, as all terms in a sum of moments on the wheel axis reduce to zero.

The moment equilibrium on the wheel axis is given by:

$$F_L.b = F_{LG}.r. \tag{21}$$

With a fluid and drag acting on the tire horizontally the measured force of the wheel in a steady-state equilibrium

$$F_M = F_D + F_{DG} + F_{LG} - F_R. \tag{22}$$

Substituting F_{DG} from Eq. (11) and F_{LG} from Eq. (21), using Eq. (21) and simplifying, the tire horizontally measured force

$$F_M = \frac{t}{2 \cdot r} F_D + \frac{a+b}{r} F_L - \frac{a}{r} F_W. \tag{23}$$

A force-measurement device with a decoupled brake measures effects of displacement drag, fluid lift and planning.

3.5 Tire-rolling resistance, fluid displacement drag, fluid planning and applied braking on the wheel

A scenario of this wheel travelling situation is presented in Fig. 7.

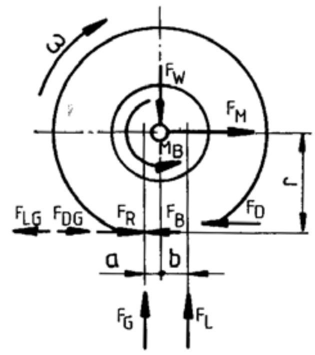

Fig. 7: *Free-rolling wheel with tire-rolling resistance, fluid displacement drag, fluid planning and applied braking.*

The equilibrium sum of the horizontal forces is given by:

$$F_M = F_B + F_D + F_{DG} + F_{LG} - F_R, \tag{24}$$

and, considering the forces expression presented before, the measured force of the wheel in a steady-state equilibrium

$$F_M = F_B + \frac{t}{2 \cdot r} F_D + \frac{a+b}{r} F_L - \frac{a}{r} F_W. \tag{25}$$

A force-measurement device reports a displacement drag, fluid lift and tire-rolling resistance in addition to the braking slip friction.

4. FRICTION EVALUATION AND CONFIDENCE

In operational friction measurements, that are typically performed during weather changes, the full runway length frequently cannot be regarded as having the same general frictional characteristic and a segmented approach is required. A sample of a segmented approach in use today is the spot measurement of parts of a runway having the same general frictional characteristics such as rain, ice or snow patches.

Friction measurements are well-known for large variability and therefore must frequently be reported with appropriate descriptive statistics. The most common statistics are mean or average friction coefficient value, sample size, standard deviation, standard error and confidence [1-2].

Averages can be propagated to higher aggregated levels provided the friction measurements are linear in nature and represent the equal or weighted sample sizes.

For friction measurement devices operating at a constant speed and producing a fixed number of samples per distance unit, the sample size is a function of the distance measured. A friction measurement must before be associated with a defined distance to reflect a consistent sample size. Accordingly, the weighted average friction coefficient value may therefore be calculated for n different distances l_i, defined by different friction coefficients μ_i, that constitute a total evaluation length L as follows:

$$\mu_m = \frac{1}{L}\sum_{i=1}^{n}(l_i \cdot \mu_i). \tag{26}$$

The standard deviation of any series of friction measurements (the most widely used dispersion measure)

$$Std = \sqrt{\sum_{i=1}^{n}(\mu_i - \mu_m)^2 / (n-1)}. \tag{27}$$

Since different friction devices report different friction coefficients values for the same surface, a standard deviation is valid only for the friction device that produced the values and, in this case, the standard error

$$Stde = Std / \sqrt{n}. \tag{28}$$

In Fig. 8 are presented two cases of standard error *vs.* number of samples for the same friction device: the average friction coefficient value of 0.66 and 0.68 for high textured surface with *Std* = 0.04 and low textured surface with *Std* = 0.01, respectively.

From the results presented it is to highlight the fact that the standard error diminishes with increase of the sample number.

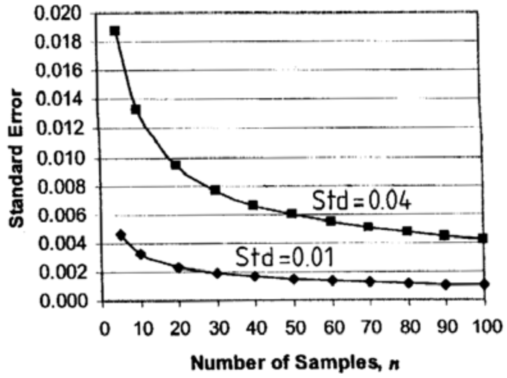

Fig. 8: *Standard error vs. number of samples.*

The confidence level expresses a probability that the average friction coefficient values fall into a confidence interval with limits as functions of the average friction value μ_m, the standard deviation *Std*, and the number n of samples. Usually, these limits are commonly set according to an imposed probability (confidence level).

In Fig. 9 the expected deviation about the mean for a 95 percent confidence level is plotted for the two cases analysed in Fig. 8.

From Fig. 9 it is obvious the fact that the confidence range interval diminishes with increase of the sample number.

For an appropriate estimation of this interval more nearly to the real one, the conditions for the vehicle planing should be more accurately predict and, as result, the crash possibilities could be easier avoided. Moreover, an appropriate estimation of this interval should be a real help for the designers in the sense to equip the vehicles with efficient security devices (*ABS*, for example) to increase the running safety on the contaminated travelled surfaces.

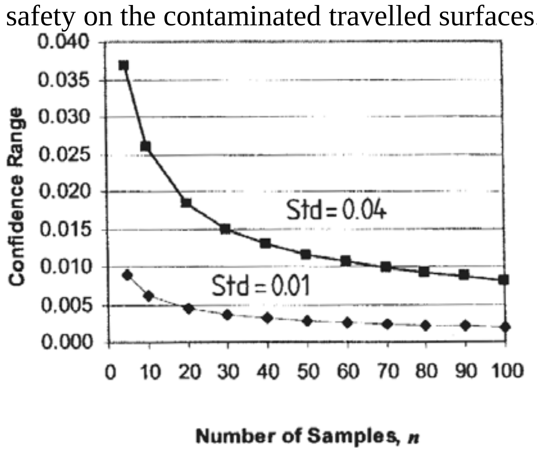

Fig. 9: *Confidence range interval for a 95 percent confidence level vs. number of samples.*

5. CONCLUSIONS

The main purpose of the paper was to approach the elementary mechanics, dynamic influences on friction by contaminants, variability of friction measures and confidence level friction measures on the contaminated travelled surfaces in the sense to increase the security of the vehicles drivers.

The results presented intend to serve as a guide for the researches, tire-surface measurement method designers, equipment manufacturers and operators in the field of measuring braking friction by public service regulations, vehicles drivers and other users of runway friction information.

6. REFERENCES

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