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ANALYSING THE UNIFORMITY OF AN AUTOMOBILE WHEELS' DISTRIBUTION OF SLIPPING AND SKIDDING

Alin-Marian Puncioiu[1], Marian Truţă[1], Marin Marinescu[1], Dănuţ Grosu[1], Valentin Vînturiş[1]

[1]Military Technical Academy, Faculty of Mechatronics and Integrated Systems for Armament, Dept. of Military Automotive and Transportation, Blvd. George Cosbuc No. 39-49, Sector 5, Bucharest 050141, Romania

Corresponding author: Truţă Marian, truta_marian@yahoo.com

Abstract: This paper is an integrated study performed over a 4x4 vehicle's transmission and propulsion system. It mainly aims at analyzing the uniformity of the distribution of the vehicle's wheels' slipping and skidding at the front and rear axles' level. When speaking about uniformity of the wheels' slipping one should understand the diminishing process of one axle's skid while the wheels of the other axle increase their slip, under certain working circumstances. Besides the theoretical notions with respect to the relative motion of the wheel vs. the road surface, the paper also presents some experimental results to consolidate the theory. Hence, the second part of the paper presents the conditions the tests have been developed under, the used testing hardware, the measuring points and so on. To accurately determine the magnitude and the variation of the wheel's slip or skid, angular speed transducers were mounted on the propeller shafts of the vehicle. Meanwhile, the real speed of the vehicle was also measured using a GPS device. Moreover, to enhance the relative motion of the wheel against the road, the tests were performed at different tire radii of the front wheels vs. the rear ones. Consequently, these differences were of 0.30 and 60 mm. The vehicle longitudinal transmission was locked so the wheels' slip or skid occurs. That was possible via a lockable inter-axle differential (which is a component of the vehicle's driveline). Aiming at getting even more parameters during the tests, a varying rolling resistance served as input. Towing a vehicle and progressively breaking the towed vehicle simulated it. Therefore, the towing force also varied, hence increasing the general drag of the towing vehicle. Studying the uniformity of the wheels' skidding and slipping is quite useful since the results either could validate and improve the known theory in this respect or could lead to new mathematical models to simulating the behavior of the wheels for certain working modes. The results are graphically presented. Such a determination could have a positive impact by optimizing the vehicle exploitation or even its modernization. The conclusion of the work is relevant since the theoretical approach is backed-up by the experimental research's results.

Key words: vehicle, slipping, skidding, transmission, transducers, dispersion.

1. INTRODUCTION

This paper main purpose is to analyze the evenness of the front and rear wheels' slipping process. Throughout the term of evenness of the wheels' slipping process we understand the homogeneity of the magnitude of the individual amounts measured for the data series of the wheels' slip or skid of an axle versus the other axle's skid within some peculiar working conditions.

This analysis has been performed to get a series of important conclusions with respect to the influence of certain factors upon the relative motion between the wheel and the running track. The conclusions we got are mainly relevant within the "technical frame" the phenomenon has been researched.

The main conditions imposed by the researcher aimed at inducing the loop power flow phenomenon along the longitudinal driveline of a 4x4 vehicle. They consisted in locking the longitudinal differential and running the vehicle with different tire radii between front and rear wheels.

The loop power-flow is the power that loads a closed loop of the transmission driveline and it is not generated by the automobile's engine or by the coasting process of the vehicle. Mathematically speaking, it is computed by multiplying the self-generated torque on some component with that component's angular speed, [1, 2].

Should be mentioned that the working mode of the vehicle was a dynamic one. Generally speaking, a dynamic regime involves rapid changing parameters of a working process. The main difference between static and dynamic mode of a vehicle consists of the difference between a relative steady working mode (when the parameters slowly vary or don't vary at all) and a turbulent mode, when the variations are wide and sudden.

To achieving pertinent analysis, mathematical notions are presented. They were used to determining the slip and skid magnitudes as well as assessing the homogeneity of a data series.

2. BASIC KINEMATICS OF THE WHEEL

When a pneumatic wheels rolls on a typical (elastic-plastic) runway (surface), complex phenomena occur. They are rather difficult to become subject of accurate mathematical expressions due to the vastness of the involved factors. Among the most important factors we find suitable to mention the tire's deformation and/or the runway surface's deformation.

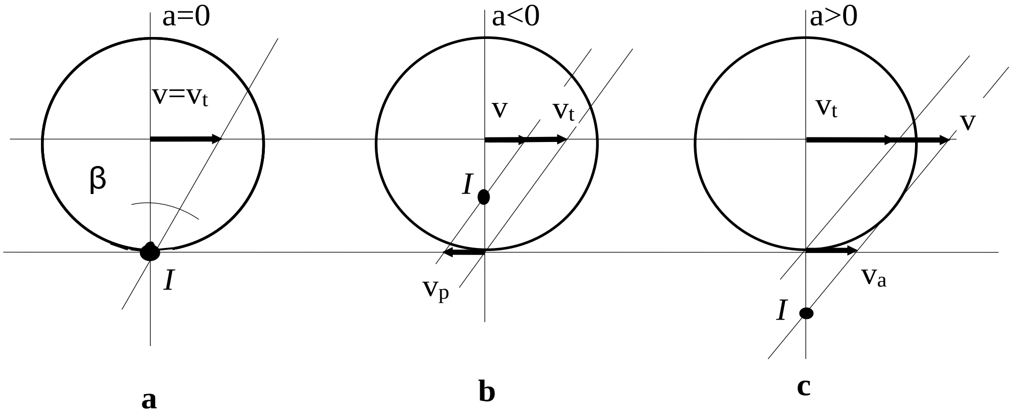

Fig. 1 Wheel's rolling situations a) ideal rolling; b) slipping rolling; c) skidding rolling; I – instant gyration center; v – real speed; v_t – theoretical speed; v_a – skidding speed; v_p – slipping speed

The following analyze assumes that both the wheel and the road's surface are completely stiff (no deformation occurs). The technical references reveal three general situations one can find the wheel in its rolling process: ideal rolling e.g. (figure 1a), slipping rolling e.g. (figure 1b) and skidding rolling e.g. (figure 1c).
The relative slip [3, 5] is defined by:

$$a = \frac{v - v_t}{v_t} \quad (1)$$

The relative skid is defined by:

$$p = \frac{v_t - v}{v_t} = 1 - a \quad (2)$$

Under certain circumstances, pure slip or pure skid could occur. Pure skid is defined by null theoretical speed ($v_t = 0$) while the skidding speed is positive ($v_a > 0$). This situation, in practice, is given by the vehicle in motion, with blocked wheels ("sledding"). Pure skid situation occurs when the vehicle is standing still (motionless) and its wheels are spinning. This case is mathematically described by a null absolute speed ($v=0$) and a positive theoretical speed ($v_t > 0$).
Considering the pneumatic tire and observing e.g. figure 1, the cinematic relation that features the wheel's roll can be also written as:

$$v = r_r \omega_d + v_\delta \quad (3)$$

where r_r is the tire rolling radii, ω_d is the angular speed of the differential's case and v_δ is the slip or skid speed, accordingly.
Analyzing Eq. 4 we can notice that all the speeds involved, i.e. the real speed, the slip or skid speed are variables depending on the tire rolling radii.

3. MATHEMATICAL ELEMENTS USED TO DETERMINE THE EVENNESS OF THE WHEEL'S SLIP

Generally speaking, a dynamic mode involves a rapid changing parameters of a working process.
The main difference between static and dynamic mode of a vehicle consists of the difference between a relative steady working mode (when the parameters slowly vary or don't vary at all) and a turbulent mode, when the variations are wide and sudden.
Knowing that the wheels' slip or skid occurred within a dynamic mode of the tested vehicle, we consider that it would be suitable to study the evenness (homogeneity) of these parameters versus the other ones as well as the homogeneity of the individual values of the time histories. A pertinent analysis of the above-mentioned parameters, corroborated with other analyses, would provide pertinent conclusions with respect to the studied phenomenon.
When dealing with measured parameters or computed ones but based on measured parameters (such are the wheels' skid or slip), the higher their degree of complexity (due to the wide range of influence factors) the higher the variation (spread factor) of the individual values. Checking the individual evenness (homogeneity) asks for measuring and analyzing the

spread and concentration with respect to the typical computed values.
Reference [3] considers the spread (variation or dispersion) as the measurable offsets of the individual values from a central (typical) value.
Knowing the nature of the studied phenomenon, one could identify a series of relevant statistic indicators that could be used to draw a series of conclusions concerning the evenness of time histories of the wheels' skid or slip. They are the spread amplitude or variation amplitude (A), the average absolute deviation ($\bar{d}_{\bar{x}}, \bar{d}_{Me}$) and the dispersion ($\sigma_{\bar{x}}^2$).
The spread amplitude (A) is defined as the difference between the highest and the lowest measured data and it is computed with [3]:

$$A = x_{\max} - x_{\min} \quad (4)$$

where $x_{\max}$ is the highest value and $x_{\min}$ is the lowest value of the series respectively.
The spread amplitude could be also expressed in percentile if used [3]:

$$A\% = \frac{x_{\max} - x_{\min}}{\bar{x}} 100 \quad (5)$$

where $\bar{x}$ is the mean value of the series. Since the spread amplitude is highly sensitive to abnormal values, it becomes useful when assessing the wheels' skid or slip only when the abnormal values have been previously removed.
Another relevant indicator for the achieved study is the average absolute deviation ($\bar{d}_{\bar{\xi}}$). It represents either the simple mean value or weighted mean value of the absolute deviation of the series elements from their centered tendency, featured by the mean value or median value.
The average absolute deviation is given by:

$$\bar{d}_{\xi} = \frac{\sum_{i=1}^{n} |x_i - \xi|}{n} \quad (6)$$

where x_i is the individual value, ξ is the central indicator of the tendency (cab be either the mean or the median value) and n is the total number of values.
The "absolute" deviations of the series terms from their central tendency eliminates the direction (sign) of the deviations both by using the absolute average deviation that uses the "modulus" and by using the dispersion.

The dispersion (σ_x^2) is computed using

$$\sigma_x^2 = \frac{\sum_{i=1}^{n} (x_i - \xi)^2}{n} \quad (7)$$

4. EXPERIMENTAL TESTS

Please To achieving the experimental data we used a military, 4WD vehicle. It has been prepared in the proper manner to have its driveline working with self-generated torque. We also simulated the variation of the drag.
The parameters that help to computing wheels' slip and skid are the theoretical and real speeds of the wheels. Computing the theoretical speed of the wheel asks for measuring the angular velocities of the longitudinal shafts of the transmission. We got the angular velocities using angular speed transducers, mounted as depicted in e.g. figure 2 [1, 4, 5]. The real speed of the vehicle was determined by a Vbox Mini GPS.
The dynamic mode of motion was simulating by increasing the drag. The increasing drag was achieved by towing a 20t vehicle that was progressively broken up to a full stop.
The magnitude of the drag was measured with the aid of strain gauge transducer that could capture the tensile force.

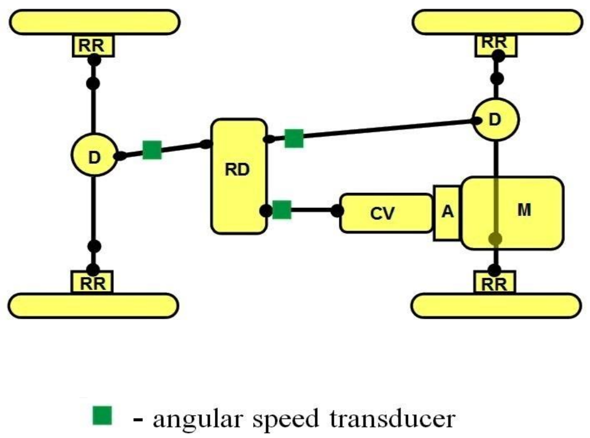

Fig. 2 Mounting the transducers to reveal the slip/skid
M – engine; A – clutch; CV – gearbox; RD – transfer case with open, lockable differential; D – transversal differential; RR – hub gear

5. EXPERIMENTAL RESULTS

Using the experimental data and computing the needed parameters we could plot their values.
Taking into account that the tests have been performed for three different situations with respect to the tire radii difference between the front and the rear axle, the paper presents four diagrams. Figure 3 depicts the time

histories of the wheels' skid and slip for the null, 30 mm and 60 mm respectively difference in tire radii. Figure 4 provides a 3D diagram that integrates the individual diagrams of figure 3.

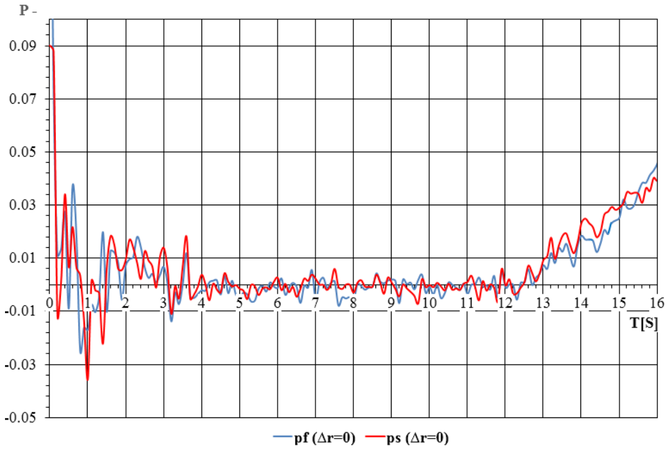

Fig. 3. Wheels' slip (Δr=0)
pf – front wheels' slip; ps – rear wheels' slip

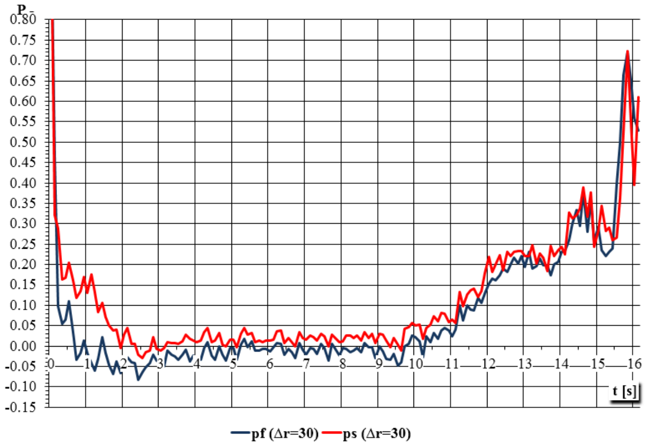

Fig. 4. Wheels' slip (Δr=30)

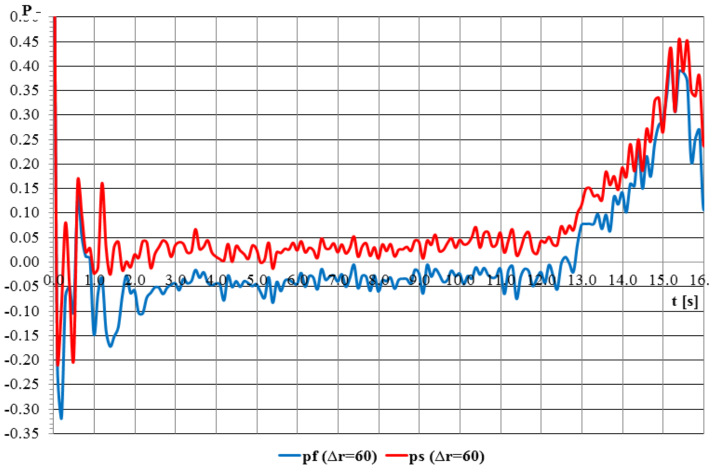

Fig. 5. Wheels' slip (Δr=60)

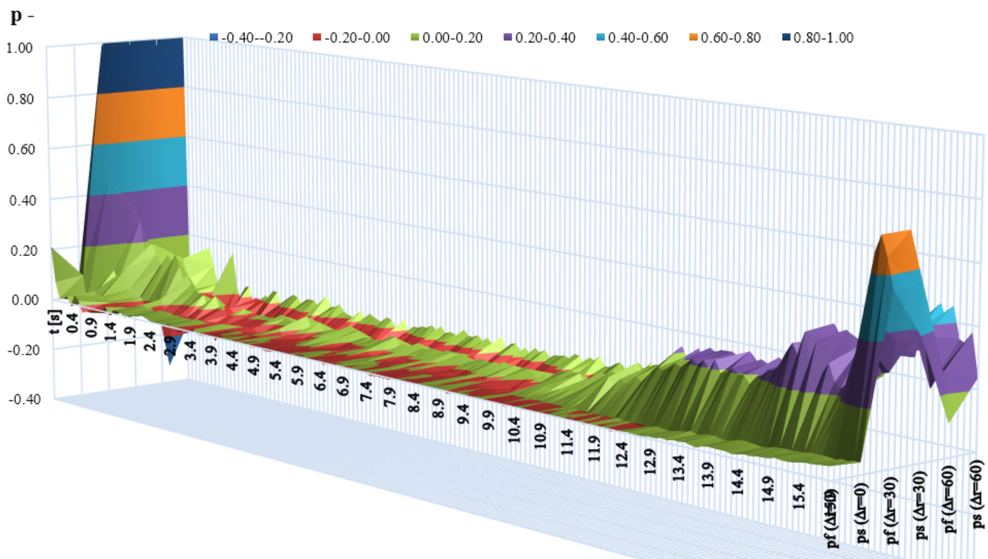

Fig. 6. Wheels' slip (Δr=0, 30, 60)

A correct interpretation of the graph depicted in e.g. figure 5 assumes S=1 for a pure slip of the wheels, S=0 for a pure roll while S= -1 means pure skid. Actually, a negative slip of the wheel means the wheels are skidding. Moreover, for values of the wanted parameters below 0.2 we can talk about micro-slip or micro-skid; hence, the slip/skid ranges between 0.2 and 1, [2].

Analyzing e.g. figure 3 and 4, one could notice that they are similar from the point of view of the general tendency. This is due to the fact that for all the situations taken into account the time histories of the analyzed parameters are similar. The variations are strong at the beginning of the test, followed by a relative even (homogenous) behavior while the end of the test provide high degrees of variation due to the drag increasing simulation. This functional pattern is mainly due to the test pattern. Thus, the test started with the shocks generated by the taking of procedure of the convoy. After reaching and maintaining the cruise speed, the towed vehicle started breaking progressively; hence, the "rough" behavior of the parameters at the end of the test.

One could notice that, for all the tests, the variation of the front and rear wheels' skid and slip has a homogenous distribution along the whole range of the time history of the tests.

Analyzing the diagrams, several conclusions can be drawn:

-If there is no tire radii difference the curves providing the front and rear wheels' skid respectively are almost overlapped. When the vehicle moves in a steady motion, the highest value is of 0.008.

-When the tire radii difference between front and rear axle is 30 mm there is no more overlapping. When the vehicle moves in a steady motion, the value of the parameters ranges within 0.05.

-For the last situation (r=60 mm) we can notice that the gap between the curves providing the skid and slip of the front and rear wheels increases. When the vehicle moves in a steady motion, the value of the parameters exceeds 0.05.

6. CONCLUSIONS

Analyzing the presented data we can reveal some ideas:

-The variation of the front and rear wheels' slip and skid is featured by uniformity (the data are homogenous) ones versus the others within the whole range of a test;

-The absolute difference between one of the axle's wheels versus the other one's, increases with the increase of the tire radii difference;

-The absolute value of the wheels' slip increases with the increase of the tire radii difference and with the increase of the drag.

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