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ANALYSIS OF TRUCK BRAKING SYSTEM IN TERMS OF CONSTRUCTION AND OPERATION

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Abstract: *Braking is the process of partial or complete reduction of the truck speed. Braking capacity is of particular importance and needs an active monitoring of the truck and the opportunity of full speed and acceleration during operation. During braking part of the accumulated kinetic energy of the vehicle is transformed into heat by friction, and part is consumed for overcoming air resistance and rolling movement.*

Efforts made in the development of actively safe vehicle braking systems are considerable. This development has reduced the braking distance by plotting braking force proportional to the static and dynamic load of axis, it has improved the stability of the truck during the braking process by introducing antilock devices with electronic control, the reliability and operational safety by increasing circuit brake actuators and further slowing proliferation.

Key words: *braking, acceleration, kinematics, electronic control.*

1. INTRODUCTION

The truck brake assembly is designed for:

- Speed reduction to a desired value or even its stopping, with the greatest decelaration and without a dangerous deviation from the trajectory;
- Imobilization of the truck while parking on a horizontal road and also on the ascents or backfalls this can climb up or down;
- Maintaining the truck speed constant in the case of climbing down long road backfalls.

The continuous growth of the truck dynamic quality and also that of the traffic have driven to emphasising the importance of the brake assembly for assuring the safety in the traffic. The efficiency of the brake assembly assures the valorization of the truck speed performances, because it depends the safe running at great speed. The more efficient the brake assembly is the greater the average running speed is also, and the performance indices are better.

During braking, part of the kinetic energy transforms into heat, and another part is lost on beating the impediments that oppose the truck drive. The brake thermal balance is presented in Table 1 [6].

Table 1

The energy balance of the process of braking.

Truck energy is lost through	Driving force to the pedal, daN					Wheel blockage	
	0	10	30	40	50	Back wheels	All wheels
Friction within brakes, %	0	61	81	84	86	49	0
Rolling resistance and transmission losses, %	87	32	14	11	8	4	0
Air resistance, %	13	7	3	3	2	2	2
Tire slip, %	0	0	2	2	4	45	98

A brake assembly needs to have the following qualities:

- *efficiency* - assessed by the deceleration obtained, and limited by the amount of adhesion between the tire and the road surface and the human biological factors (high responsiveness to acceleration);
- *stability* - the quality of the truck guidance in the braking, depending on the brake type, on the nature and condition of the track, the

performances required etc.; it is very important in terms of traffic;

- *fidelity* - quality of the brakes to get identical accelerations to all wheels, for a determined drive effort, in any road conditions and load conditions. A great influence on this quality have the external agents (humidity, temperature), the technical working brakes conditions and especially the stability coefficient of the friction gaskets;
- *comfort* - the quality which contributes to increased road safety at a high degree of comfort (gradual braking, low pedal effort for a race judiciously chosen, the absence of noise and vibration) not require overly driver's attention, thus reducing driver's fatigue [3].

The vehicle stability under braking depends on the uniformity of distribution of braking forces on the left and right wheels, the stability of braking torque forces in case of possible variations of the friction coefficient (typically between 0.28 and 0.30) and a tendency of the brakes for self-locking. If the braking torque does not deviate from the design value with more than 10-15% then braking stability can be easily maintained by using the steering wheel [5], [8], [9].

Due to the frequent use of the braking device (about two, three brake/km in a city with an average circulation intensity), the effort required by the brake actuation must be within certain limits. A great effort leads to rapid fatigue of the driver, increasing reaction time and finally to low decelerations. Conversely, if the drive pedal effort is too low, it would create a danger that at an emergency braking to produce abnormal blocking of the braked wheels.

Conservation of braking qualities of the truck is given if the braking forces realized by the brakes themself at a given effort, applied on the control element, are maintained constant in all operating conditions encountered in service[9].

It must be noticed that the current friction linings (except ceramic – metal ones) have a coefficient of friction that varies with temperature and their condition. The thermal regime of the brakes in case of normal use should not lead to temperatures above 300 °C, to ensure as far as possible a constant coefficient of friction. To achieve this temperature, control brakes must ensure evacuation of thermal energy that is produced during braking.

Quiet operation is ensured by taking constructive measures that prevent the production of vibration caused by the drums or discs and the brake shoes or pads, or due to other brake components. In order to achieve this characteristic, all these bodies must be sufficiently rigid [1], [2], [4].

2. CLASSIFICATION OF THE BRAKE ASSEMBLIES

The classification of the brake assemblies is mainly based on their utility:

- The main brake system, we meet it also named the main brake or service brake. Typically, the service brake is named in operation foot brake because of the way it is driven. This braking system must allow reducing the vehicle speed to the desired value, including its stop, regardless of speed and state of charge. Main brake must act on all the trucks wheels.
- The safety braking system, met also under the name of emergency brake, serves to supplement the main brake in case of failure. The emergency brake has to be operated by the driver without taking both hands off the wheel.
- The stationary braking system or the parking brake has the role to keepthe vehicle immobilized on a slope in the absence of the driver for an indefinite period of time. Because of the manual actuation of the parking brake, this was given the name handbrake. The parking brake must have its own command, independent of the main brake.
- The auxiliary braking system is a supplementary brake having the same role as the main brake, being used in case of necessity and complementing with its effect the safety brake.
- The additional braking system or retarder is designed to maintain a constant vehicle speed, down along long slopes without the prolonged use of the brake. This braking system is used in trucks with large mass or specifically intended to be used in mountainous areas or rugged terrain. The additional braking contributes to reducing the wear of the main brake and to increase the traffic safety [9].

3. CONDITIONS IMPOSED ON THE BRAKE SYSTEM

Brake systems must comply with the following conditions:

- to be able of certain imposed decelerations;
- to assure the truck stability while braking;
- braking to be progressive, without shocks;
- to achieve fair distribution of the braking effort to axes;
- not to need a big effort from the driver to actuate it;
- conservation of the braking qualities of the truck in all encountered conditions in use;
- to assure heat eviction that raises during braking;
- safety while working in all conditions;
- rapid entry into operation;
- braking is not to be influenced by the unevenness of the road (due to the vertical displacement of the wheel) and by the turning of the truck;
- to allow the stopping of the truck on a slope even in the case of longer stationing;
- not to permit that oil and dirt reach the friction surfaces;
- the brake force to action in both moving senses of the truck;
- brake to be actioned only with the intervention of the driver;
- not to permit the concomitant actuation of the brake pedal and of the acceleration pedal;
- to have a simple and cheap construction.

Provided that security requirements imposed on truck design, the main braking system to allow a maximum deceleration of 6 – 6.5 m/s^2 for cars and 6 m/s^2 for trucks. Recommended safety braking deceleration must equal at least 30% of the main brake deceleration.

In the case of air brake systems in motor vehicles tanks must be used to allow that after eight consecutive drives carried to the end position of the control device, residual pressure in the tank does not fall below the level required to ensure security of the prescribed braking. The tanks on trailers must be provided in a way that after the same number of eight drives of the towing vehicle service brake, the level of the energy provided to the elements that use it, will not fall below half the value corresponding to the first service brake application. It is not allowed to fill the tank during the tests and auxiliary tanks should be insulated. Ensuring stability of the truck movement, especially articulated vehicles and road trains during braking and the need for most efficient possible use of the braking forces that can be achieved by the vehicle brakes, impose restrictive conditions on the response time of the braking system. The most important requirements for the response time of the braking systems are the maximum allowed phase difference between the entry into service of the brakes from the same axes is between the limits 0.05...0.1 s, the maximum delay entry into service of the most deprived brake axes of the truck, in terms of braking distance compared to the control element must be 0.15...0.35 s, and the maximum delay of the entry into operation of the most deprived brake components of an auto-train axis should not exceed 0.6 s.

4. CALCULATION OF THE BRAKING MECHANISM

At present, for trucks the brakeengaged is made with pneumatic or hydro-pneumatic mechanisms.

4.1. Calculation of brakes

The dimensioning of brakes is made, normally, in an empirical manner starting from similar existing solutions, verified in practice [2].

In the case of disc brakes a particular importance have the thermal loads that are much higher than in the case of drum brakes, and their cooling is faster because of their construction, with rapid variations in time and with very high temperature gradients. It follows, therefore, that sizing of drums and discs is made on the ground of stiffness and thermal loads. The braking, especially intensive braking, involves the transformation in a very short time of an amount of mechanical energy into heat. In the case of the braking of a truck with the deceleration a_f, the power P_f that is absorbed by the brakes is obtained from relation (1):

$$P_f = \frac{G_a}{g} \cdot a_{fmax} \cdot V_{max} \qquad (1)$$

where:

- G_a - is the trucks mass;
- g - gravity acceleration (9,807 m/s^2);

- V_{max} - is the maximum speed of the truck.

Deceleration during braking can get to 6 - 8 m/s^2, so resulting that the power that the brakes must absorb often surpasses the power of the engine 4 - 5 times, sometimes this value gets to grow to a value that is 9 - 10 times larger [3].

The big amount of heat that comes out while braking contributes to the worsening of the braking qualities and emphasizing the wear of the friction gaskets.

While brakes get warmed up we can often notice a diminishing of their effectiveness, due to the so called phenomenon of "fading". This decrease is explained by the decrease of the friction coefficient of materials, of the friction gaskets due to evaporation at heating of the binder substance and the formation of a greasy layer on the gasket surface. Also during braking there is a modification of the dimensions of the component parts due to their warming up. Wearing of the friction gaskets grows faster with the raise of the temperature. After numerous tests with different types of gaskets, it was concluded that the wearing of the gasket is 2-5 times more intense in the case of a raise in temperature from 100˚C to 300˚C. Modern friction gaskets can take for a long period of time a temperature of 350 – 500˚C. The temperature permissible for the receptor cylinder seals is 170 – 190˚C, and the temperature of the tire in the rim contact zone should not exceed 90 – 95˚C [5].

In order to obtain, during the braking of the truck, the deceleration a_f we will need a braking force F_f that can be calculated with the help of relation (2), (a_f =8 m/s^2; g=9.807 m/s^2).

$$F_f=\frac{G_a}{g}\cdot a_f \quad (2)$$

By changing the data in relation (2) we obtain $F_f = 1,61 \times 10^4$ N.

4.1.1. Checking the mechanical loads of the brakes

Check the mechanical brakes is estimated using parameters, ones of the most used are the pressure on the surface of the friction gasket, friction specific mechanical work, specific strength and specific charge.

a) Pressure on the surface of the friction gasket [7]. Sustainability of friction is assessed by means of pressure between the gasket and the disc. It is assumed that the pressure on the disk is uniform and is considered a medium pressure which is calculated by the relation:

$$p_{med}=\frac{N_a}{\propto(r_e^2-r_i^2)} \quad (3)$$

where:

- N_a- is the reaction of the braking disk on the braking gaskets;
- r_e- is the outer radius of the braking disk;
- r_i- is the inner radius of the braking disk;
- α- is the angle at center expressed in radians (0.8726 rad).

By replacing the data in relation (3), we get p_{med} = 8 daN/cm^2. The reaction N_a is calculated with the relation:

$$N_a=\frac{1}{2}p\alpha(r_e^2-r_i^2) \quad (4)$$

b) Friction specific mechanical work. Sustainability of friction gaskets is assessed with the help of the friction specific mechanical work given by the relationship:

$$L_s=\frac{L_f}{\Sigma A} \quad (5)$$

where:

- L_f - the mechanical work of braking forces;
- ΣA – surface of friction gaskets of all brakes ($\Sigma A = 0.062\ m^2$).

By replacing the data in relation (5) we get: L_s= 8.6daN/cm^2.

The mechanical work of the braking forces is determined with the relation:

$$L_f=\frac{1}{26}\frac{G_a}{g}V^2 \quad (6)$$

By replacing the data in relation (6) we get L_f= 5,37daN/cm^2.

The surface of a braking gasket is calculated with the relation:

$$A=\frac{1}{2}\alpha(r_e^2-r_i^2)[mm^2] \quad (7)$$

c) Specific braking strength [7]. The necessary braking strength to brake a truck from the maximum speed until stopping, with a maximum deceleration a_{fmax} is given by the relation (a_{fmax} =8 m/s^2; V_{max} = 90 km/h):

$$P_f=\frac{G_a}{g}\cdot a_{fmax}\cdot V_{max} \quad (8)$$

Table 2

Friction specific mechanical work at automobile braking [7].

Type of vehicle	Speed V at which braking starts until stop Km/h	Specific mechanical work L_f daN/cm²
Auto-truck	30	5 -10
	V_{max}	40 - 250

By replacing the data in relation (8), we get P_f= 0.93 kW/cm², and the specific braking strength is calculated with the relation:

$$P_s = v \cdot \frac{G_a}{g \cdot \sum A} \cdot a_{fmax} \cdot V_{max} \quad (9)$$

By replacing the data in relation (9), we get P_s=0,61kW/cm². The admissible specific strength depends on the type of the truck and the type of the brakes, therefore for the disk brakes of trucks $P_s \leq 0.75 \div 0.95$ kW/cm².

4.1.2. Heat calculation of brakes

Heat calculation of a vehicle brake can be made only on the basis of experimental data in the actual conditions of cooling of the brakes in the braking process. In the design phase it is appropriate to consider the characteristic parameters of existing constructions that have been verified in practice. Thermal calculations based on such data, even if not accurately reflect the thermal solicitation on the brakes of the designed vehicle, and so being a means of avoiding too large discrepancies between dimensioning and operation requirements [8], [9].

At ***intensive braking*** it is considered that the entire amount of heat emitted contributes to the temperature growth of the braking mechanism, i.e. taken by the disk. Making the heat balance of the braking from the speed *V* until the stopping of the vehicle we get:

$$\Delta_r = \frac{G_l \cdot V^2}{108500 \cdot \xi \cdot c_a n_f \cdot G_t} \quad (10)$$

where:

- G_t- weight of brake disk (25 kg);
- ξ-coefficient that represents the fraction of the produced heat and taken by the disk (99%);
- c_a-mass heat extracted from Table 3;
- n_f– number of braked wheels (4);
- G_l- total weight of the loaded automobile, expressed in N.

By replacing data in relation (10), we get $\Delta_r = 9.71°C$. It is recommended that in the case of intensive braking from *30 km/h* until stopping, the temperature raise Δ_r should not be greater than 15°C, thing that is viable in our case study.

In the case of *prolonged braking* it is also considered the heat exchange with the external environment. Maximum temperature of the disk can be calculated with the relation:

$$\tau_{dmax} = 56{,}5 \frac{\chi \cdot \rho_d}{\rho} \sqrt{\frac{V}{3{,}6} \cdot \frac{1}{\pi \cdot a_{f\,max} \cdot \alpha_t}} \, °C \quad (11)$$

where:

- x - partition coefficient of heat between the brake pad and disc;
- α_t- thermal diffusion in m²/s $\left(\alpha_t = \frac{\lambda}{c\rho}\right)$;
- λ – thermal conductivity;
- ρ – material density;
- ρ_d – density of heat flux.

The density of heat flux ρ_d is calculated with the relation (12):

$$\rho_d = \frac{G_a}{g \cdot \sum Ai} \cdot \frac{V}{3{,}6} \cdot \frac{a_f}{427} \text{kcal/cm}^2\text{s} \quad (12)$$

By replacing data in relation (11) we get $\tau_{dmax}=247^0C$. According to the regulation no. 13 of C.E.E. of U.N.O., temperatures in brakes should not go over 300^0C.

4.2. Construction of the braking system

4.2.1. Pneumo-hidraulic actioning [7]

A pneumo-hidraulic braking system has the following components (Figure 1):

Service braking. Air/hydraulic pedal type with three independent circuits: one to activate the front axle braking components, the other to activate the rear axle components and, the third one for braking the trailer.

Exhaust brake. Three types of exhaust brake controls are provided. Each of them can be selected through the proper switch on the instrument panel, according to the different road types/conditions.

Parking brake. It consists of the hand distributor pneumatic control and spring cylinder which operates on rear wheel brakes to lock them. In case of failure, this system brakes the vehicle automatically.

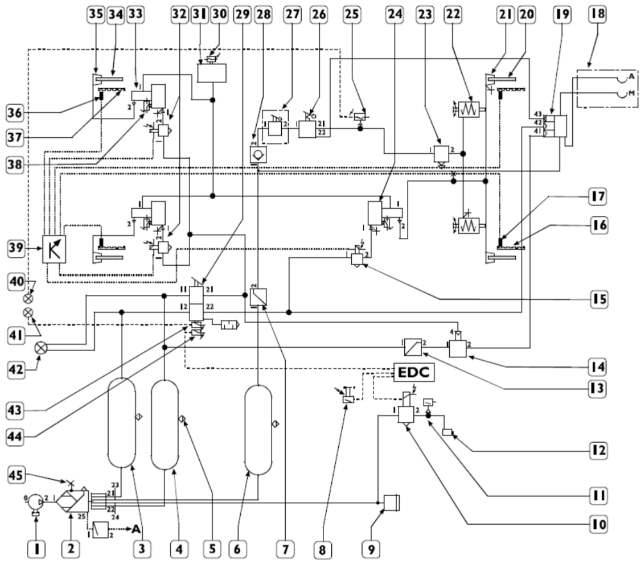

Fig. 1. Pneumo-hidraulic braking system
1. Compressor; 2. Air Processing Unit; 3.15 l rear axle air tank; 4.15 l axle air tank; 5.Manual condensate bleeder valve; 6.15 l air tank for parking brake and trailer recharge; 7.Pressure reducer for parking circuit and trailer recharge; 8. Exhaust brake push button; 9. Safety valve (optional); 10. Exhaust brake solenoid valve; 11. Trailer braking control pressure switch;12. Exhaust brake valve control cylinder; 13. Trailer control pressure reducer; 14.Trailer braking control augmenter valve; 15.ABS solenoid valve; 16.Phonic wheel; 17. Speed sensor; 18. Trailer coupling half-joints; 19.Triple control servo distributor for trailer; 20. Brake disc; 21. Brake caliper; 22. Spring cylinder for parking brake; 23. Dump valve for parking brake; 24. Air/hydraulic converter; 25. Low pressure switch indication for handbrake on; 26. Hand distributor for parking brake control; 27. Safety hand distributor (optional); 28.Parking circuit single-acting valve; 29. Autorestrictive coaxial duplex distributor; 30.Low oil level warning light; 31.Oil tank; 32.ABS solenoid valves; 33.Air/hydraulic converter;34. Brake disc; 35. Brake caliper; 36. Speed sensor; 37. Phonic wheel; 38.Converter extra travel warning light; 39.ABS ECU; 40.Parking brake led; 41. STOP light led; 42. Axle/rear axle pressure gauge; 43. Stop light relay control switch; 44. Switch indicating brake on for EDC; 45. Air control socket; A.To service circuit.

Table 3

Characteristics of materials used in construction of brake disks [6], [9].

Nr. crt.	Material	Density ρ[kg/m^3]	Thermal conductivity λ[kcal/mhC]	Mass heat c[kcal/kgC]
1.	Cast iron	7200	20	0,15
2.	Steel	7850	36	0,12
3.	Organic seal Jurid 197	1000	0,99	0,30
4.	Sintered seal Jurid 730	2500	8,6	0,15

4.2.2. Pneumatic actioning [8]

A pneumatic braking system has the following components (Figure 2):

Service braking. Pneumatically controlled pedal type operates on all the wheels and the trailer. It features two separate sections, one to activate the front axle braking components, the other for the rear axle components. A third section, assisting the two distributor sections, brakes the trailer. The duplex distributor controls the two separate sections and the triple control servo distributor that in its turn controls the third section. Should a failure occur in one section, the pneumatic system sectioning enables the others to efficiently operate.

Emergency braking.This is combined with the parking braking. The double circuit system enables the braking of one axle even when there is a failure in the braking of the other axle, by means of the service brake pedal and the parking hand lever.

Retarding braking.The engine brake used in engines is composed of a hydraulically controlled mechanism that cancels the exhaust valve clearance. By applying this mechanism, at the end of the compression phase, a few degrees before the T.D.C., the exhaust valves open slightly with a consequent reduction in the pressure formed in the cylinder. This takes advantage of the braking torque of the compression phase but without having the following return thrust on the piston.

Parking braking. This is mechanical and actuated through the hand distributor set at the end of its stroke. It operates on the rear wheels of the truck discharging the air from the spring section of the pneumatic cylinder and the servo distributor control section, thus locking the trailer or semi-trailer wheels. From the driver's seat it is possible to check whether the trailer is able, with the trailer brakes released, to ensure the efficiency of the combined tractor-trailer parking brake[7].

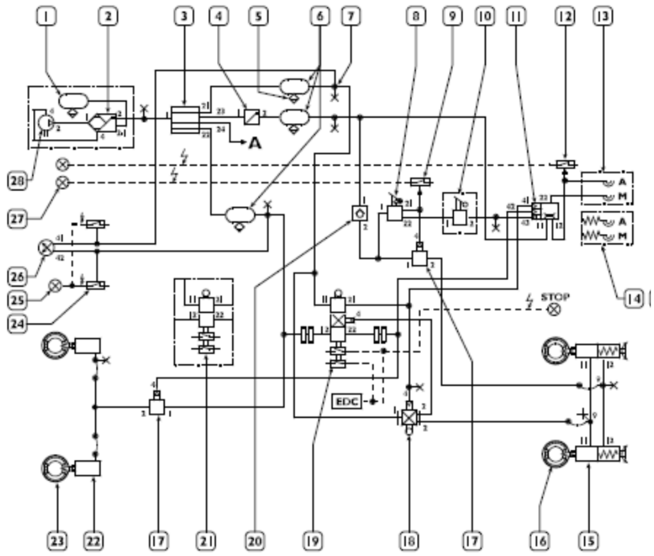

Fig. 2. Pneumatic braking system

1. 5 litre air regeneration tank; 2. Drier with built-in 11 bar regulator; 3.Four-way safety valve; 4. 8.5 bar pressure reducing valve; 5. Manual condensate bleeder valve; 6.20 litre air tank; 7.Pressure control intake;8. Hand distributor for parking brake control; 9. Indicator switch for parking brake on (5.5 ± 0.6 bar); 10. Hand distributor for only trailer brake control (optional); 11. Triple control servo distributor for trailer braking; 12. 16.4 bar low pressure switch (optional); 13. "ISO" half-coupling for truck; 14."ISO" half-coupling for tractor; 15. Combined brake cylinder; 16. Drum brake; 17. Relay valve; 18. Brake corrector; 19. Duplex distributor for truck; 20. Check valve; 21. Duplex distributor for tractor; 22. Diaphragm brake cylinder; 23. Front drum brake; 24.Low pressure indicator switch;25.Low pressure warning light; 26.Gauge; 27. Parking brake warning light; 28.Energy Saving compressor; A.To service circuit.

5. KINETO-DYNAMICS OF THE BRAKING PROCESS

Braking is the process of partially or totally reducing the vehicle speed. It is achieved by generating in the wheel braking mechanisms a braking moment that causes the appearance of a braking force in the wheels facing the direction of the vehicle speed, but the opposite sense. Finding and comparing the truck braking capacity is made with the help of the absolute maximum deceleration (a_f) or relative (d_f), braking time (t_f) and the minimum braking space (S_f), according to the initial speed of the vehicle. To determine the sizes above in the bibliography are presented analytical relationships. The relationship set refers to a vehicle that has ideal distribution of braking forces, or relative decelerations ($d_f = a_f / g$) achieved by each axle have equal size. How in reality this happens only in special cases, in the construction of braking systems are introduced adjusters of the axle brake force depending on the dynamic or static load.

In this case, to maintain the stability of the vehicle within the braking system to a minimum space of stopping, there was introduced at international level (Regulation ECE-UNO no. 13 the 05 amendment set), the diagram of the repartition of the braking forces on the axis in compatibility conditions for the constructing elements and use of the vehicle.

Norms related to the braking capacity, with validity in our country, pays special attention to the effectiveness of the braking devices evaluated based on the braking space. They include requirements related to the construction characteristics of the braking devices, and braking performance test methods for each category (vehicles and trailers are classified in categories M, N, and O). Table 4 presents the set braking performances of braking systems for motor vehicles belonging to categories M and N.

5.1. Braking capacity parameters

The parameters characterizing the vehicle braking are: deceleration, braking time and space. In assessing the braking ability, we make use of the minimum braking space and the maximum deceleration [7].

5.1.1. Determination of deceleration

a) The case in which both axles are braking. The maximum deceleration, in the case where the wheel brakes of both axles is obtained when all wheels reach the limit of adhesion at the same time. Maximum deceleration produced this way is called *maximum possible deceleration* or *ideal maximum deceleration* and it is expressed by the equation:

$$(d_f)_{maxp} = \left(\frac{d_v}{d_t}\right)_{maxp} = g(\varphi cos\alpha \pm sin\alpha)[m/s^2] \quad (13)$$

where :

- $g = 9{,}81$ m/s^2 is gravitational acceleration;
- φ - adhesion coefficient;
- α – the road's longitudinal angle of inclination (for a horizontal road $\alpha=0$)

b) The case in which only front axle's wheels brake. Maximum deceleration, in case when only the front axle's wheels brake, is obtained when the braked wheels reach the limit of adhesion while freely running wheels of the rear axle. Maximum deceleration obtained in these conditions is expressed by the equation:

$$(d_f)_{maxf} = \left(\frac{d_v}{d_t}\right)_{maxf} = g\left(\varphi\frac{\frac{b}{L}}{1-\varphi\frac{h_g}{L}}cos\alpha \pm sin\alpha\right)[m/s^2] \quad (14)$$

where:

- b, h_g are the coordonates of the vehicle's weight center;
- L – the vehicle's wheelbase.

c) ***The case in which only rear axle's wheels brake.*** The maximum deceleration, in the case in which only the wheels of the rear axle brakes, is obtained when the wheels reach the limit of adherence of the braked while the wheels of the front axle is free to run. Maximum deceleration obtained in these conditions is expressed by the equation:

$$(d_f)_{maxs} = \left(\frac{d_v}{d_t}\right)_{maxs} = g\left(\varphi\frac{\frac{a}{L}}{1+\varphi\frac{h_g}{L}}cos\alpha \pm sin\alpha\right)[m/s^2] \quad (15)$$

where:

- a, h_g are the coordinates of the vehicle's weight centre.

Table 4

Performances of braking systems for vehicles as stipulated in STAS 11960-89.

Vehicle		Trial speed [km/h]	Maxim effort on pedal [daN]	Calculus formulae for the braking space [m]	Medium deceleration [m/s²]
Type	Category				
Cars	M_1	80	50	$S_f \leq 0,1V + \frac{V^2}{150}$	5,8
Busses with a total mass up to 5.000 kg	M_2	60	70	$S_f \leq 0,1V + \frac{V^2}{130}$	5
Busses with a total mass over 5.000 kg	M_3				
Trucks with a total mass up to 3.500 kg	N_1	70	70	$S_f \leq 0,1V + \frac{V^2}{130}$	4,4
Trucks with a total mass between 3.500 and 12.000 kg	N_2	50			
Trucks with a total mass over 12.000 kg	N_3	40			

5.1.2. Determination of the braking space

Among the parameters of braking capacity, the braking space in the most direct causes braking qualities closely related to road safety. On both axles braking the minimum braking space, obtained when tangential reactions simultaneously reach the limit of grip, the braking distance is called *the minimum possible braking space*, and is determined, in case of braking between speeds $V_1>V_2$, with the relation:

$$S_{fminp} = \frac{(V_1^2-V_2^2)}{26g(\varphi\cos\alpha\pm\sin\alpha)}[m] \quad (16)$$

or, in case of braking until stopping (V_2=0), horizontally:

$$S_{fminp} = \frac{V_1^2}{26g\varphi}[m] \quad (17)$$

in which the speed is expressed in km/h.

From the relation of the minimum braking space until stopping the vehicle results that it is proportional to the square of the initial velocity. If the speed increases by 22.5%, the minimum braking space increases by 50%. Also, over the minimum braking space has a big influence the coefficient of adhesion. Thus, for a level road, the decrease of the coefficient of adhesion by 30% causes an increase of the minimum braking space by 43%.

5.1.3. Determination of braking time

The braking time is of importance especially in work process analysis of braking devices and less is used for assessing the braking ability of vehicles. In case of both axles braking, the braking time is called *minimum possible braking time*, and is determined, in case of braking between speeds $V_1>V_2$, by the relation:

$$t_{fminp} = \frac{(V_1-V_2)}{3,6g(\varphi\cos\alpha\pm\sin\alpha)}[s] \quad (18)$$

or, in case of braking until stopping (V_2=0), horizontally:

$$t_{f\min p} = \frac{V_1}{3,6g\varphi}[s] \quad (19)$$

in which speed is expressed in km/h.

5.2. Brake force distribution between the vehicle axels

Considering the vehicle moving straight and being braked in terms of the braking forces to the wheels simultaneous the adherence limit (ideal case), normal reactions on the axis have the following expressions:

- for the front axle:

$$Z_1 = G_1 + G_a\frac{h_g}{L}\varphi \quad (20)$$

- for the back axle:

$$Z_2 = G_2 - G_a \frac{h_g}{L} \varphi \qquad (21)$$

where:

- G_a, G_1, G_2 are respectively the vehicle weight and the static weights distributed to the front or rear decks;
- h_g –height of the weight centre;
- L – the vehicle wheelbase;
- φ – adhesion coefficient.

In case the braking performance requires a certain relative deceleration (d_f), the above relationships become:

- for the front axle:

$$Z_1 = G_1 + G_a \frac{h_g}{L} d_f \qquad (22)$$

- for the rear axle:

$$Z_2 = G_2 - G_a \frac{h_g}{L} d_f \qquad (23)$$

In conformation with the relations (20) and (21), respectively the relations (22) and (23), we obtain the maximum tangential reactions while braking under the form:

$$F_{f1} = \varphi Z_1 [\mathrm{N}] \qquad (24)$$

and:

$$F_{f2} = \varphi Z_2 [\mathrm{N}] \qquad (25)$$

In this case the specific tangential braking force or the adhesion coefficient is:

- for the front axle:

$$\xi = \frac{F_{f1}}{Z_1} = \frac{F_{f1}}{G_1 + G_a \frac{h_g}{L} d_f} \qquad (26)$$

- for the rear axle:

$$\xi = \frac{F_{f2}}{Z_2} = \frac{F_{f2}}{G_2 - G_a \frac{h_g}{L} d_f} \qquad (27)$$

If we denote by i_F the distribution ratio of the braking force on the front axle ($i_F = F_{f1}/F_f$) and by i_S the distribution ratio of the static load on the front axle ($i_S = G_1/G_a$), *the adhesion coefficient* results in the following form:

- for the front axle:

$$\xi_1 = \frac{\frac{F_{f1}}{G_a d_f}}{\frac{G_1}{G_a d_f} + \frac{h_g}{L} d_f} = \frac{i_F}{\frac{i_S}{d_f} + \frac{h_g}{L}} \qquad (28)$$

- for the rear axle:

$$\xi_2 = \frac{\frac{F_{f2}}{G_a d_f}}{\frac{G_2}{G_a d_f} - \frac{h_g}{L} d_f} = \frac{1 - i_F}{\frac{1 - i_S}{d_f} + \frac{h_g}{L}} \qquad (29)$$

From the relations of the two adherence coefficients while braking we can deduce the following:

- If $\xi_1 > \xi_2$ while braking the front axle wheels get to the adherence limit before the ones on the rear axle, respectively while braking the front axle's wheels are over-braked in opposition with the rear axle's wheels.
- If $\xi_1 = \xi_2$ while braking the wheels of both axles reach the adherence limit at the same time.
- If $\xi_1 < \xi_2$ while braking the rear axle wheels get to the adherence limit before the ones on the front axle, respectively while braking the rear axle wheels are over-braked in opposition with the front axle wheels.

6. CONCLUSIONS

The braking system for commercial vehicles fulfills all the conditions of road safety, being able to work a long time without premature wear and in optimal conditions.

Vehicles with a capacity exceeding 5 tons use hydro-pneumatic and pneumatic mechanisms.

ABS braking system electronically monitors the pneumatic braking mechanism, enabling the optimum braking even if the road surface is wet or covered with snow or ice. This system is equipped with a sub ASR, which aims to exclude wheel slip, enabling braking stable vehicle even in curves.

Since ABS braking system came virtually to the end of its development, nowadays commercial vehicles have been equipped with EBS brake systems, which include both the subsystem ABS and certain new subsystems with role of stemming selectively, only on wheels deemed necessary to be braked so that it maintains the stability in all conditions on the road. EBS braking signal is transmitted electrically, ensuring a much higher response rate than for ABS. EBS increases traffic safety for both vehicle and trailer. The service brake interacts with the auxiliary brakes to improve both safety and efficiency. It is standard on trucks equipped with air suspension and can be installed on some configurations with leaf springs. When the driver presses the brake pedal, brake signals are transmitted to the control unit EBS. Sensors that measure wheel speed and brake lining wear send information to the control unit, which determines the brake pressure on each axle and distributed to each wheel. EBS also has a pneumatic backup system. This system works independently and kicks in if the electronic system is not supplied with electricity.

EBS interacts with other systems of the trucks as EDC, the engine control system, and from where, through CAN line receives data on speed, load and throttle position, or automatic transmission and the brakes for slowing down, it works with the automatic drive.

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ANALIZA SISTEMULUI DE FRÂNARE AL CAMIOANELOR DIN PUNCT DE VEDERE CONSTRUCTIV ȘI FUNCȚIONAL

Rezumat : Frânarea este procesul prin care se reduce parțial sau total viteza de deplasare a vehiculului. Capacitatea de frânare prezintă o importanță deosebită ce determină direct necesitatea activă a automobilului şi posibilitatea de monitorizare integrală a vitezei şi accelerației acestuia în timpul exploatării. În timpul frânării o parte din energia cinetică acumulată de autovehicul se transformă în energie termică prin frecare, iar o parte se consumă pentru învingerea rezistențelor la rulare și a aerului care se opune mişcării.

Eforturile depuse pentru evoluția sistemului de frânare în cadrul siguranței active a automobilului sunt considerabile. Astfel s-a micșorat spațiul de frânare prin reprezentarea forțelor de frânare proporționale cu sarcina statică și dinamică a punții, s-au înbunătățit stabilitatea mişcării şi reversabilitatea automobilului în timpul procesului de frânare prin introducerea dispozitivelor de antiblocare cu comandă electronică, fiabilitatea şi siguranța în superiorizare prin mărirea de circuite de acționare şi proliferarea frânelor suplimentare pentru încetinire.

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