THE STUDY OF THE CONSTRUCTION AND OPERATION OF THE BRAKING SYSTEMS USED FOR MINERAL SUBSTANCES HAULING VEHICLES

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ABSTRACT: The paper deals with the modern braking systems of mineral substances hauling vehicles. A description of the technical and constructive characteristics of the braking systems as well as of the means of testing and checking their efficiency is also brought forward. Testing the braking systems is necessary to verify the braking performance of vehicles in order to ensure the driving safety.

Key-words: braking systems, auto-truck, braking forces measurement, testing, checking

1. THEORETICAL CONSIDERATIONS

1.1. Generalities regarding the braking system

While the history of more than 130 years of vehicles' breaking systems has proven the success of the systems, hauling has changed significantly during this whole period of time. The speed and the charging loads have definitely increased, and the drivers' experience behind the wheel has changed a lot. The new braking systems have proactively approached this set of changes. Braking is the process of partially or totally reducing the driving speed of the vehicle. The importance of the braking capacity directly determines the active need of the vehicle and the entire possibility of monitoring its speed and acceleration during operation. A part of the cinematic energy accumulated by the vehicle is transformed into thermal cinematic energy through

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friction, while a part is used to overcome the resistances to rolling and air which opposes the movement.

In order to reduce the speed of the vehicle, forces which oppose the movement need to be created. As some of the forwarding resistances have reduced effects, and the resistance to acceleration, in the case of braking becomes the active force, it results therefore the necessity for the vehicle to be foreseen with such devices which are able to create forces opposite to the movement direction. These are called braking forces the values of which need to be large enough in order to be regulated by the driver depending on the needs. The braking forces are created by the braking mechanisms included in the braking systems of the vehicle. Any vehicle needs to be fit with independent braking systems which are required to act quickly and efficiently.

1.2. Classification and characteristics of braking systems

The classification of braking devices is made according to their use, constructive particularities and the installation place of the braking mechanism, the energy source used to drive them and the type / particularities of the transmission.

Depending on their use, the braking systems of a vehicle are:

- the service brake (the main foot brake) which acts on all the wheels, and its role is to reduce the speed of the vehicle until it comes to a halt, independent on the used speed, the hauled load or the inclination of the road. The main brake is required to act upon all the wheels of the vehicle;
- the safety brake (safety, emergency, shut-off) has the role of supplying the service brake in case it breaks down, its operation has to allow for the vehicle to be stopped without lifting the hands off the wheel;
- the parking brake has the role of maintaining the vehicle temporarily immobilised in the absence of the driver. The parking brake is required to have its own command independent of the service brake;
- the auxiliary braking system is an additional brake having the same role as the service brake and it is used when required, when its effect is cumulated to the one of the service brake;
- the role of the retarder is to maintain the speed of the vehicle constant, when the vehicle is descending long slopes in the case of large mass vehicles or those vehicles destined to be used in rough terrain or mountainous in order to avoid the overburdening of the service brake;
- the vehicle engine brake is not a system, mechanism or gear. It happens when shifting into the immediate inferior gear and its role is not to let the wheels lock in conditions of reduced grip conditions (i.e. verglas, ice, square rocks, etc.), which could lead to the loss of control and direction.
- lorries' engine brake is realised by closing the evacuation gallery and the fuel admission from the fuel injection pump; its operation is pneumatic.

According to the constructive particularities of the braking mechanism, the braking devices are classified on the geometric form of the revolving and fixed parts of the actual brake. According to the form of the revolving part the following brake types are known: drum brake; disk brake; combined brakes. According to the form of the fixed parts brakes may be: shoe brakes, with plaques, straps, disks or combined.

Considering the installation place of the braking mechanism the following types are met: wheel brakes and transmission brakes.

Considering the type of transmission the following types of brakes are met: mechanical; hydraulic; pneumatic; electric; combined; servo transmission brakes.

The role of the slowing down devices (speed limiter, retarder) or the additional braking system is to maintain the vehicle at a constant speed for a longer period of time while it descends long slopes without using the service brake. Very useful in mountainous regions with long slopes, where the intensive heat and wear of the main braking system comes into play, the retarder increases the average movement speed, reduces the wear of the tyres, of the motor and keeps the main braking system ready to operate.

The slowing down devices are classified according to the operation principle: i.e. mechanical, pneumatic, aerodynamic, hydro-mechanic and electromagnetic.

Hydraulic transmission braking devices are presently the most used ones for vehicles. These are installed on all road vehicles, small capacity lorries and buses and a on a large number of medium capacity busses and lorries as well as on a series tractors. With all the advantages the hydraulic transmission brings forward, due to the impossibility to realise an increased transmission ratio, the force applied by the driver through the pedal, does not always ensure the necessary braking efficiency. Therefore, the use of the hydraulic transmission in vehicles with a total weight larger than 3500 kg requires the compulsory introduction of a servo mechanism.

Air operated braking system. Air brakes or compressed air braking system is a type of friction brake for vehicles where compressed air is used at the push of a piston to apply the required braking pressure to stop a vehicle.

This type of braking systems are used on large and heavy vehicles, especially on those hauling more trailers which need to be connected to the braking system.

Fig. 1. Air operated braking system

The retarder is an additional braking system which acts directly upon the transmission. The electromagnetic retarder does not imply friction but braking using the magnetic field. It is installed on the gear box, on the differential or on the transmission. The operation of the retarder is made with the hand brake or the pedal.

Double control optimises the use of the retarder without requiring any additional attention from the drivers.

The characteristics of quarry hauling vehicles:

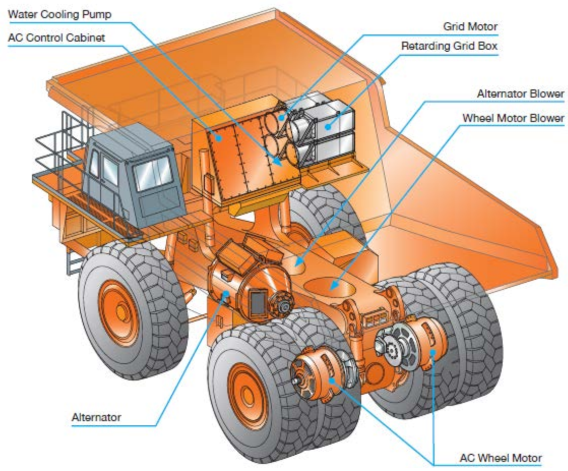

Fig. 2. HITACHI EH3500AC quarry vehicle

Quarry vehicles manufactured lately reflects the advance in technology recorded especially in all the control, operation, surveillance and operation domains. This advance is closely related on the involvement and implication of the informational technology within the vehicle, allowing for most of the operations to be controlled and carried out automatically. The main characteristics offered by the two main manufacturers of quarry hauling vehicles manufacturers, namely Komatsu and Caterpillar are hereinafter presented.

HITACHI EH3500AC dump truck vehicles.

Hitachi AC driving technology ensures a superior performance, with increased top speeds, a better rising capacity and a powerful retard. The braking system on the rigid truck is hydraulically operated with oil cooled multi-disk packs on the rear and dried on the front brakes.

Hitachi AC driving systems provide more force than the DC driving system. The complete retard capacity means that the vehicle may be completely stopped without applying the service brake. AC DRIVE control. The braking combination service brake with electric inhibitors is automatically applied through AC traction system in order to stop the truck at speeds smaller than 0.5 km/h. The driver may stop the truck using only the retarder pedal, resulting therefore a larger serving interval of the service brakes.

Fig. 3. AC braking system

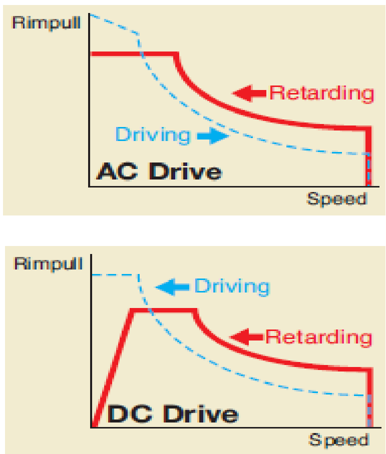

Fig. 4. AC DRIVE Braking system

1.3. Maintenance, testing, and checking the braking system

It is necessary to test the brakes in order to check the performance of all the braking systems provided on a vehicle, in order to be sure that safety is provided and maintained. The designer of a vehicle shall determine the performance level of the braking system. The user has the duty of ensuring that the vehicle is adequate to operate in the conditions it was destined for. Brakes' testing is carried out periodically.

The effects of speed, loading and gradient: a vehicle stops differently in different speed conditions, charging load or slope. It is to be understood why and the means in which the conditions affect the stopping capacity. The effect the speed has on the stopping distance: the faster a vehicle moves the more it will take to come to a halt. Twice the speed results in approximately four times the necessary breaking distance.

The effect the charging load has on the stopping distance: a loaded vehicle requires a longer distance to come to a halt than an empty vehicle. It is due to the fact that the deceleration ratio of the brakes is smaller for a loaded vehicle than for an empty one. Is the designed braking ratio is given as a percentage of the charging load and tested empty, then the measured braking ratio will not be the same. Global assessment of the braking performances shall be corrupted. Fortunately it is easy to make the transformation from the loaded braking ratio to an empty one. Force = weight x deceleration. The maximum developed braking force may be assumed to be constant for any charging load conditions, with the condition of it being developing. Therefore: weight loaded x deceleration loaded = own weight x deceleration unloaded

Loaded weight and empty weight are standard information.

The effect the gradient has on the stopping distance: a vehicle moving on a slope will require a larger distance to come to a halt than a vehicle moving at the same speed on a plane surface.

2. TECHNICAL CONDITIONS REGARDING THE EFFICIENCY CHECK OF THE BRAKING SYSTEM OF ROAD VEHICLES

Efficiency check of the braking system of road vehicles supposes for the braking coefficients realized by the service and park brake to be checked, as well as the check of the unbalance between the braking forces at the wheels connected to the same axle for the service as well as for the park brake.

2.1. The braking coefficient

Represents the ratio between the sum of the braking forces at the wheels upon which the brake acts, the efficiency of which is checked and the weight of the road vehicle presented for the technical inspection:

$$C = \frac{F}{G} \times 100\ (\%) \qquad (1)$$

where: F (daN) – the sum of the braking forces at the wheels upon which the brake acts the efficiency of which is checked; G (daN) – the weight of the road vehicle presented for the technical inspection.

There are laws which regulate the minimum admissible braking values for road vehicles for the service brake as well as for the park brake, the maximum admissible values for the unbalance between the braking forces for the wheels connected to the same axle for road vehicles for the service brake and for the park brake. For vehicles which are not equipped with a servo brake it is compulsory to check the efficiency of the service brake by operating it with an effort to push the pedal which shall not exceed the determined value considering the charging load of the vehicle:

$$F_p = F_{p\max} \times \left(\frac{m_{ef}}{m_{tot}} \right), \quad \text{(daN)} \tag{2}$$

where: $F_{p\max}$ – is the maximum admissible pedal operating effort; m_{ef} - the effective weight of the inspected vehicle; m_{tot} – represents the total approved maximum weight of the inspected vehicle.

2.2. The unbalance between the braking forces

Is determined using the following relation:

$$C_f = \frac{\sum_{i=1}^{n} F_{is} + F_{id}}{G} \times 100\,(\%) \tag{3}$$

where: $F_{\max}$ (daN) – is the braking force at the wheel recording the superior braking force; $F_{\min}$ (daN) – is the braking force at the wheel recording the inferior braking force.

Considering the case of the vehicles the maximum constructive speed of which is maximum 25 km/h, tractors, auto-trailer, special vehicles, the constructive characteristics of which do not allow for the check of the efficiency of the braking system on the roller braking stand, the check is made through functional trials on course, measuring the maximum deceleration at a sudden brake from a speed of 30 km/h (or, be it the case, from the maximum constructive speed) for the service brake and 15 km/h for the parking brake.

2.3. Trial methodology of the breaking systems of M, N, and O category vehicles with a total approved weight larger than a 3.5t using a roller braking bench

2.3.1 Pneumatic, hydro-pneumatic and completely hydraulic braking systems, vehicle loaded at the Maximum Total Approved Weight

Determining the *coefficient of braking* of a vehicle loaded at the MTAW does not require any extrapolation, resulting simply from the following relation:

$$C_f = \frac{\sum_{i=1}^{n} F_{is} + F_{id}}{G} \times 100\,(\%) \tag{4}$$

where: F_{is} (daN) – is the braking force at the wheels on the left side of the axle i; F_{id} (daN) – is the braking force at the wheels on the right side of the axle i; n – the number of axles; G (daN) – the weight of the vehicle presented for the periodic technical inspection.

2.3.2. Pneumatic, hydro-pneumatic, and completely hydraulic braking systems – one point measuring method

This extrapolation method supposes the existence of pressure testing valves of the compressed air tank controlling the braking circuit on each axle or of the brake cylinders, as the case may be. During the check on each axle, at least 30% of the maximum nominal pressure of the braking system needs to be obtained through adequately loading the vehicle or by simulating the load. In order to determine the *coefficient of braking* it is required to know the following parameters:

a) the value of the maximum braking forces for the loading level of the presented vehicle (are obtained on the roller braking bench);
b) the values of the pressures in the compressed air tanks controlling the braking circuit on each axle which is checked or the ones in the braking cylinders (depending on the place of the check valve) to which the maximum braking forces are obtained for the loading level with which the vehicle was presented for the periodic technical inspection (are obtained through measuring during friction on the roller braking bench, connecting the pressure measuring gauges);
c) the value / values of the extrapolation pressure for each point are taken over or are determined depending on the existent data on the plate of the automated braking regulator depending on the charging load.

For a certain axle, maximum brake forces are obtained when bloking the brake bench or, if it does not block, by reading on the display the maximum values. The extrapolation factors for each axle are determined according to the following formula:

$$E_i = \frac{p_{ex} - 0{,}4}{p_i - 0{,}4} \tag{5}$$

where: i – is the number of checked axles; p_{ex} – is the value of the extrapolation pressure; p_i – the value of the measured pressure to which the maximum brake forces on axle *i* were obtained.

The value of the *coefficient of braking* is determined using the following formula:

$$C_f = \frac{(F_{is} + F_{id}) \times E_i + ... + (F_{ns} + F_{nd}) \times E_n}{G} \times 100\% \quad (6)$$

where: F_{is} (daN) – is the brake force of the wheels on the left side of axle *i*; F_{id} (daN) – is the brake force of the wheels on the right side of axle *i*; E_i – is the extrapolation factor for axle *i*; *G* (daN) – the weight of the vehicle loaded at the MTAW; *n* – the number of axles.

If the value of the determined braking coefficient is smaller than the minimum admissible value, then the vehicle should be presented for the periodic technical inspection loaded at at least 50% of the maximum load.

3. PRACTICAL EXAMPLE. THE CHECK OF THE BRAKE SYSTEM OF THE SCHMITZ SPR24 2002 SEMI-TRAILER

Fig. 5. Testing the brake system of the SCHMITZ SPR24 2002 trailer

The determination of unbalances, the coefficient of braking and the coefficient of braking after extrapolation.

SEMITRAILER						
Parameter /nr. Axle, Brake		1,2	2,2	2,3		**Maximum Values**
Maximum brake force left	daN	1050	1085	1268		
Maximum brake force right	daN	1185	1243	1124		
Roling rezisting force left	daN	45	53	39		
Roling rezisting force right	daN	47	53	49		
Max P1	Bar	0,00	0,00	0,00		
Max P2	Bar	2,00	1,90	2,00		
Pedometer maximum force	daN	-	-	-		<=50
Brakeing force difference	%	11	13	11		<=30
Total braking force	daN				**6954**	
Total brakeing efficiency	%				**56**	<=45
		1,2	2,2	3,2		
Maximum brake force left	daN	989	1010	1289		
Maximum brake force right	daN	1156	1173	1148		
Max P1	Bar	0,00	0,00	0,00		
Max P2	Bar	0,00	0,00	0,00		
Pedometer maximum force	daN	-	-	-		<=0
Brakeing force difference	%	14	14	11		<=50
Total braking force	daN				6767	
Total brakeing efficiency	%				54	>=16
Weight at Test = 12766,9 Kg						

Fig. 6. Braking parameters

Vehicle type	Make/type	Year	coef. Servo Brake	Park	F.Fr1 sleft+right	F.Fr2 left+right	F.Fr3 left+right	p1	p2	p3	det. Extrapolated coef.	d1	d2	d3	weight kg
semi-trailer O4	SCHMITZ S02	2012	53	54	583	561	569	1.77	1.77	1.91	33.62	19	27	10	4993
N3 Lorry	RENAULT 440DXI	2006	61	31	3514	1763	2695	3.3	3.3	3.3	61.67	6	17	12	8880
semi-trailer O4	SCHMITZ SPR24	2005	54	53	2043	2154	2303	1.8	2.1	1.9	65.97	13	15	14	12347
semi-trailer O4	SCHMITZ S01	2007	52	56	2016	2197	2246	1.5	2.1	2.1	62.86	10	9	11	12550
semi-trailer O4	SCHMITZ SPR24	2002	56	54	2235	2328	2392	2	1.9	2	68.79	11	13	11	12767
semi-trailer O4	SCHMITZ S01	2007	55	54	2368	2490	2483	2.2	2.3	2	64.68	9	9	15	13540
semi-trailer O4	SCHMITZ S04	2011	53	54	2393	2391	2545	3.75	3.86	4.78	44.88	8	8	7	14027

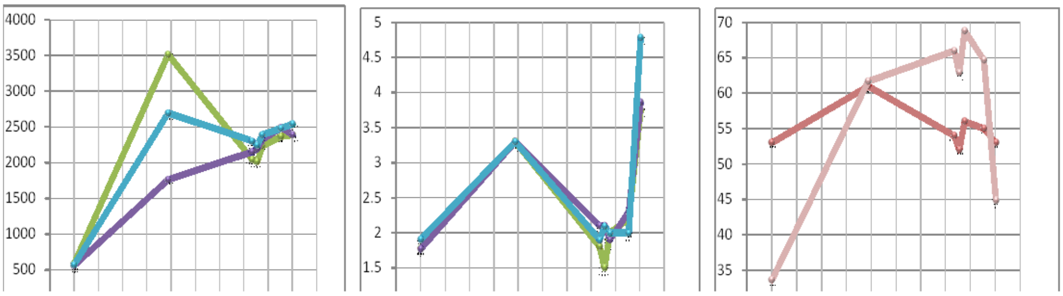

Fig. 7. Comparison to other types of semi-trailers

Brake system failures

- The wheels remain under the action of the brake or overheat.
- Brakes a render ineffective if air makes its way in the hydraulic installation.
- The incomplete release of the park brake leads to increased fuel consumption and excessive heating of the drums of the rear wheels.
- The pedal's freeplay is too small due to the insufficient space between the shoes and the disk.
- -The pedal's freeplay is too large due to the existence of air within the hydraulic installation.
- If air pressure inside the braking installation drops or if it is lost then the automated brake of the rear wheels occurs. In order to unlock the rear wheels the arming rods of the accumulation resorts in the receiving cylinders are operated upon, which leads to the ineffectiveness of the emergency brake.
- If the air line between the truck and trailer breaks, the trailer brakes at full capacity.

Maintenance of the brake system

Maintenance may be defined as the number of required operations undertaken to keep the system within the safety operating conditions and prevent break downs. It is applied at the working place, working equipments or transport means (e.g. a ship).

Preventive – or proactive – the maintenance is carried out for a functional preservation. This type of activity is usually planned and scheduled.

Corrective – or reactive – maintenance is to repair in order to make it operational again. This is a non-scheduled task, unplanned, usually associated to larger risks and an increased risk level.

The maintenance of the hydraulic brake system comprises the following works: hydraulic installation tightness control; checking and adding liquid in the reservoir of the main pump; checking and regulating the freeplay between the rod and the piston of the pump; the evacuation of air from the installation and checking the wear of braking gaskets; checking and setting the run between the shoes and the drum.

4. CONCLUSIONS

Recommendations for quarry machineries

Brakes need to be designed and tested according to the norms and regulations in force, testing is carried out periodically.

If there is the need for equipments which operate on slopes higher than 10% the following additional criteria need to be considered:

1. "The service braking system" is capable of stopping and maintaining the mobile equipment stationary in the shortest time possible after the retardant has broken down. This is carried out with:
   - A minimum net deceleration of 0.6 m/s^2 (6% g) in order to stop on a

slope. For instance, in order to cross a slope of 20% (1:5) the service brake need to be capable of maintaining an approximate average deceleration of 2.6 m/s^2 (26% g) during the stopping period (2.0 m/s^2 to exceed the gravitational energy and 0.6 m/s^2 for net deceleration).
- An average deceleration of min. 1.85 m/s^2 (18.5% g) for the main performance of the service brake.

2. "The secondary braking system", is capable of stopping and keeping stationary the mobile equipment's, in the shortest time possible after the failure of the retarder or the failure of any other component of the service brake. It is realized with:
   - A minimum net deceleration of 0.3 m/s^2 (3% g) for stopping on an incline. For instance, in order to cross a 20% degree, the secondary brakes need to be capable to maintain an average deceleration of approximately 2.3 m/s^2 during the stopping period (2.0 m/s^2 to exceed the gravitational energy and 0.3 m/s^2 for a net deceleration).
   - An average deceleration of minimum 1.3 m/s^2 (13% g) for the main performance of the secondary brake.
3. Testing and analysis of braking should also consider the maximum loads, speeds and classes, the energy absorption requirements, and the heat influence for the inclinations following to be crossed; the failure of a simulated component and the reduced pressure of the system.
4. For the pressure systems, the maximum braking performance of the secondary brake should be reached if two of the following events occur simultaneously:
   - a failure of a unique common component of the braking system
   - after five consecutive operations of the pedal (the operator)
   - the system pressure reaches the alarm level of the operator.
5. During or after the brake is operated or after automatically applying the brake, the mobile equipment is still capable to come to a halt and maintained on the cross class.
6. The integrity of the braking systems shall be assessed in relation to the equivalent standards and the failure means and the analysis of the effects or other similar techniques used for risk assessment.

Recommendations destined for quarry operators:

1. Verifying the transport routes and identifying the trucks travelling on slopes larger than 10%.
2. When mobile equipments operate on slopes larger than 10% the manufacturer should be contacted fin order to have a confirmation that the mobile equipment is safe and may be used in the specified conditions.
3. The operators need to be instructed that the maximum values of the inclination of the slopes do not consider the existent variations of the conditions of the road or the distances which may affect the moving speed. Other factors such as visibility, traffic and weather might also be

considered.

4. If the information is not provided by the manufacturer, then the mine should carry out its own assessment and test to make sure that the above described criteria are met.
5. The design of transport roads with 10% slopes or less as much as possible.

The constructors have made great efforts for the evolution of the braking system considering automotive active safety. Therefore the braking space has been reduced by the representation of the braking forces proportional to the static load and the dynamics of the axle, the balance of the movement and the reversibility of the vehicle during the braking process have been improved by introducing the electronic command anti blocking systems, operational reliability and safety by the increase the operating circuits and proliferating additional brakes to slow down.

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