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ANALYSIS AND SELECTION OF BRAKES FOR HEAVY VEHICLES

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Abstract *The paper presents an analysis of the foundation brakes currently in use on heavy motor vehicles. The results indicate the conditions in which currently available brakes are developed by heavy motor vehicles industry and point to changes in the future. Such changes may be related to legislation, newly available brake types and requirements in vehicle usage. An algorithm for heavy motor vehicle brake analysis and selection is proposed. The paper concludes with some indications of the future requirements for the heavy vehicle industry in view of changes in foundation brakes design in an effort to improve road traffic safety.*

1. INTRODUCTION

Current heavy motor vehicles are completely different, even compared to their immediate predecessors. A vast variety of characteristics, hardly known until a short time ago, plays an important role in design of heavy vehicles today. The products quality, long lasting reliability, technical characteristics and performance, technological solutions, comfort, control, complex on-board systems, electronic control units, noise reduction, emission control and on-board information systems are pointed out here. Some of these systems are of great importance, some are necessary, while braking systems continue to be the most important of all the systems, no matter how important other components are.

The intensity of sudden braking for heavy vehicles must be of the same order as for passenger vehicles because of the traffic homogeneity and increase in road safety. The objective is to gain deceleration of *8* $[m/s^2]$ on heavy vehicles, the same amount as on passenger vehicles. The intensity of sudden braking at high speeds may be defined through average moment achieved during braking until the vehicle stops.

Two basic conceptions of brake mechanisms are in use on modern heavy motor vehicles: different variants of drum brakes and disc brakes. Both types of brakes have certain advantages and disadvantages that significantly depend on vehicle's category, type and purpose. Although, for a long time, disc brakes have been used more in passenger vehicles and drum brakes in heavy vehicles, the intense development in this area in the world has brought changes in relative ratio of application of each of brakes design. Ten years ago, disc brakes were slowly introduced in heavy vehicles, with the exception of heavy vehicles with small carrying capacity (having total weight up to 4 or 5 [t]) in which disc brakes were applied at the front axles (with hydraulic transmission system). Tests related to development of disc brakes for heavy vehicles having hydraulic and pneumatic control, carried out in all developed European countries, in the USA and in Japan, have given significant results.

The first disc brakes were developed in 1956 (for Citroen DS). They were designed because the front axle drum brakes were not able to stop the vehicle due to fading effect. The first application of disc brakes in wide range of heavy vehicles has not appeared until the 1988. Main advantages of disk brakes are: short braking path, resistance to the fading effect and greater thermal drainage. These characteristics, together with very small right/left wheel difference, give a sensation of comfort and a factor of safety, not achieved earlier on heavy vehicles. All of this has lead to technical progress regarding power of engines applied on heavy vehicles. Bigger costs of disc brakes come from the complexity of the brake calipers and, above all, due to small produced quantities. However, it should be pointed out that the additional costs are in direct relation to the increase in safety.

2. TRENDS IN DEVELOPMENT OF BRAKES FOR HEAVY VEHICLES

The technical problem is not reduced only to the choice: disc or drum brakes? Disc brakes for passenger vehicles are not directly applicable to heavy vehicles, even when there is a possibility to proportionally increase dimensions. In fact, space available on heavy vehicles is twelve times smaller then on passenger vehicles, for same amount of specific brake power. The result of this is that the operating conditions for heavy vehicles are especially hard in respect to thermal field. Technical difficulties originating from this are:

1. Life of brake linings

It is required that the life of brake linings for heavy

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vehicles should be ten times longer then for passenger vehicles. In order to meet these requirements, huge improvements were made in respect to linings materials, so their life is now comparable to the life of drum brakes.

2. Thermal environment of bearings and tires

Operating temperatures are higher and the disc is situated very closely to these sensitive components.

3. Great range of operating conditions

Depends on driver's activity and balance of articulated vehicle.

4. Brake force distribution between axles

It is necessary to provide correct distribution of brake energy for all operating conditions.

Disc brakes having multiple brake cylinders (three or four at each side of the disc) and rigid brake calipers are provided for vehicles with great masses, especially for heavy tractors for civil engineering and mining. In last few years, considerably better mechanically, i.e. pneumatically controlled calipers of disc brakes have emerged. Two typical solutions are shown in Figure 1. Even being very complex, these designs may relatively easily be adjusted to space available. Designs of so called ventilated discs are specially used as brakes for heavy mass vehicles. A toothed ring used as a sensor for number of revolutions is integrated with the disc. Brake calipers for heavy vehicles have a problem with connecting the calipers to the carrying elements of the vehicle.

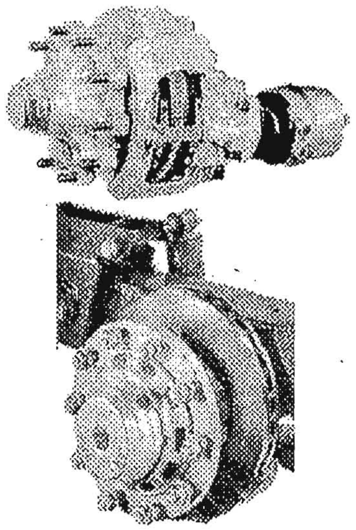


Figure 1: *Blw and SAF disc brakes in electronic pneumatic brake systems [7]*

In Yugoslavia, the basic requirements regarding brake systems for motor vehicles and trailers are established, first of all, by the low of basics of road traffic safety. The *ECE-13* book of regulations has special importance in establishing uniform regulations for vehicle homologation regarding braking. This book of regulations applies to transportation devices traveling at speeds greater than *25[km/h]*. Service brake systems for N_2 and N_3 category vehicles (heavy vehicles having total weight between *3.5[t]* and *12[t]* and exceeding *12[t]*) must be investigated under conditions given in Table 1.

Table 1

	Vehicle category	N_2	N_3
"O" type testing with engaged clutch	v	60 km/h	
	s≤	$0.15 \cdot v + \frac{v^2}{130}$	
	j_m≥	5,0 m/s^2	
"O" type testing with disengaged clutch	v=80%v_{max} not higher than	100 km/h	90 km/h
	s≤	$0.15 \cdot v + \frac{v^2}{103.5}$	$0.15 \cdot v + \frac{v^2}{103.5}$
	j_m≥	4,0 m/s^2	4,0 m/s^2
	Force applied at the pedal	70 daN	

Introduction of international positive regulations defining vehicle braking properties and safety parameters has lead to development of heavy vehicles' braking systems with:

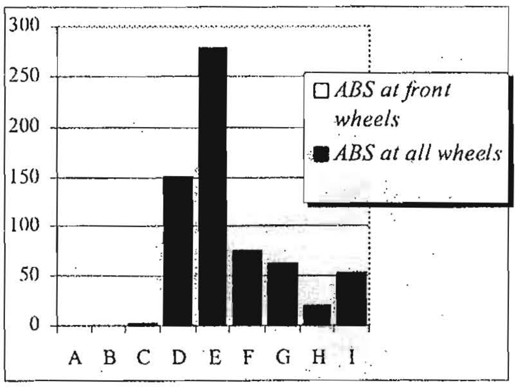
- high reliability (minimal possibility of malfunction),
- increased efficiency and
- possibility of braking force regulation dependent on load conditions (*ALB*) and wheel roll conditions (*ABS*).

Anti-lock braking device can be built in transfer mechanism of the braking system in different ways, in order to regulate pressure introduced into the brake cylinder of one or more wheels. Thus, various effects in respect to stability of the vehicle during braking and to braking system performance are achieved. Regulation of only some wheels enables the use of cheaper anti-lock braking systems, but gives the lower level of performances. Simple anti-lock braking systems usually create problems in reaction speed, which are fully expressed during transition from the slippery road onto the road with good adherence. Therefore, the vehicle can not achieve deceleration in accordance to adherence available, so the braking path is longer.

A four channel anti-lock braking systems with independent and direct regulation of each wheel are frequently used in heavy vehicles with high total weight, articulated vehicles included. Such systems provide considerable reduction of the braking path, but very often have unfavorable characteristics regarding stability of the braking vehicle.

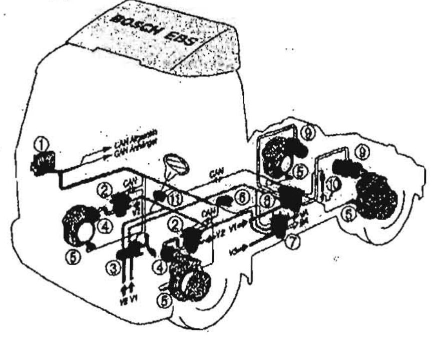
It should be noticed that positive regulations require the building in of any additional component into the braking system to be carried out in such a way that, in the case of its malfunction, the system can normally operate as if that component does not exist.

The results of statistical analysis of the use of anti-lock braking systems (*ABS*) on heavy vehicles with total weight exceeding *3.5[t]*. The vehicles were divided into the classes marked with *A* to *I*, the meaning of which is explained in Figure 2. All wheels anti-lock braking systems are convincingly the most applied solutions in majority of categories studied. *A* and *B* category vehicles do not have such systems.



A- Heavy vehicles with total weight of 3.5 to 6.5[t]
B- Heavy vehicles with total weight of 6.5 to 10[t]
C- Heavy vehicles with total weight of 10 to 14[t]
D- Heavy vehicles with total weight of 14 to 19[t]
E- Heavy vehicles with 3 axles
F- Heavy vehicles with 4 axles
G-Articulated lorries with total weight over 3.5t
H-Articulated lorries with 3 axles
I- 4x4 drive vehicles with total weight over 3.5t

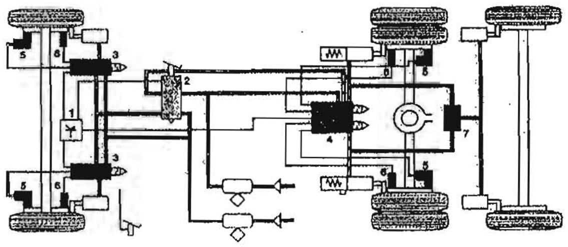
***Figure 2:** Application of ABS systems on heavy vehicles*



1- Control unit
2- Single-channel pressure regulation module
3- Master brake cylinder
4- Membrane brake cylinder
5-Number of revolution sensor
6-Transversal acceleration sensor
7- Trailer command valve
8- Two-channel pressure regulation valve
9-Combined brake cylinders
10- Load sensor
11- Steering wheel angle of rotation sensor
V_1... V_3 - Air reservoirs
LF- Pneumatic elastic elements
VA-Reserve line
BA-Brake pipeline

***Figure 3:** Bosch electronic braking system of an articulated lorry [6]*

Two typical installations of an articulated lorry (Figure 3) and of an articulated bus (Figure 4) are presented in order to get the orientation in anti-lock braking systems realizations, that is in building in of these devices into the transfer mechanisms of the braking systems whose activation forces of brake mechanisms are supplied from external energy sources, most frequently from compressed air.



1-Electronic control unit
2- Brake valve
3-Pressure modulus (single-channel)
4-Pressure modulus (double-channel)
5- Number of revolutions sensor
6-Linen wear sensor
7-Select-low valve

***Figure 4:** Electronic brake system of a bus [8]*

3. ALGORITHM FOR SELECTION OF BRAKES FOR HEAVY VEHICLES

The selection algorithm includes a sequence of activities conducted by the suppliers, heavy vehicles producers and the users.

Calculation methods for brakes have experienced intense development mostly due to development of computer techniques. All of this has brought numeric methods to the spotlight, as basic calculation methods without which the development of a great number of products could not be imagined in technologically advanced countries. These methods provide quick analysis of a great number of different combinations, as well as the selection of the most favorable one (optimization). Numerical methods are approximate and require reliable data for expression of boundary conditions. Thus, there is their immediate connection to braking mechanism tests that give high accuracy and quality information due to the advancements in measuring equipment, processing and data analysis techniques. Accordingly, time required to develop new brake elements is considerably reduced. A comparison between the temperature changes on the disc hub and on the disc itself acquired by numerical modeling and the test-bench testing is illustrated in Figure 5. Good agreement between achieved results is obvious.

During selection of brakes for heavy category vehicles, producers of the vehicles most frequently do not develop brakes as executive mechanisms, but they are constitutive part of the components producer *know-how*.

CAD studies have provided the building in of the best solution for various vehicles depending on empty vehicle's mass, axle type, steering mechanism, shock-absorber, wheel diameter, tire type and dimensions, roll radius, numerous versions of air suspensions having protective rubber with different overall dimensions. Great effort is applied to preserve the components standards, geometry and connections in order to improve economic results (Figure 6).

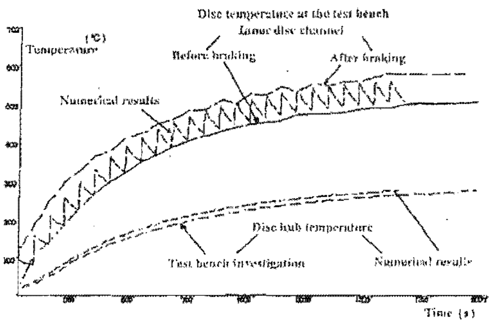


Figure 5: *Comparison between the disc temperatures achieved by numeric methods and at the test-bench [5]*

Detailed tests (several million kilometers) are conducted on vehicles in different development stages: test units, hybrid vehicles, prototypes, and definitively shaped vehicles. Test include endurance tests, downward drive on mountain roads, on and off road combined drives at high speeds, city drive, winter tests, etc. Special attention is given to temperature measurements in the wheel structure, including the temperatures of the wheel hub, a kingpin and bearing lubrication oil. Stresses are measured during tests with strain gauges and compared with the results of numeric calculation methods.

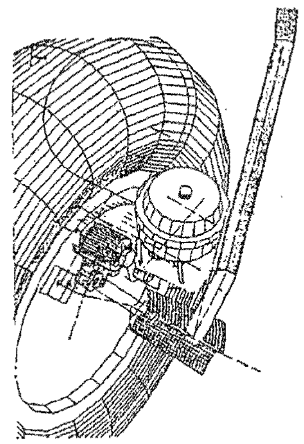


Figure 6: *An example of CAD design for fitting the adopted brake into the vehicle [4]*

In the next phase, a correction of spotted defects is done. One phenomenon, not easily solved, is the squeezing noise at low pressures that occurs during the vehicle testing at different temperature conditions, when vehicle brakes at low speed. This problem exists in all brake types, especially if asbestos friction materials are used, and it is specially pointed out in huge drum brakes.

4. CONCLUSIONS

Analysis of the brake mechanisms applied in current world production of heavy vehicles has confirmed the irrepressible trend of application of disc brakes which has completely pushed out the drum brakes in some categories of heavy vehicles. Advantages of disc brakes can be finally summarized: higher braking efficiency, absence of the *fading* effect, correct dissipation of accumulated heat due to ventilation effect, quick change of the brake pads. Fully assisted electronic brake system is present in all heavy vehicles with huge total weight and, thanks to the *ABS* system, maximal possible braking forces limited by the road quality are achieved, and the road traffic safety is considerably higher.

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