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TRENDS IN THE DEVELOPMENT OF BRAKE SYSTEMS OF THE AGRICULTURAL TRACTORS AND TRAILERS

Jasna Glišović [1], Jovanka Lukić [2], Danijela Miloradović [3], Slavica Mačužić [4]

Summary: *As agricultural tractor size and speeds have increased during recent years, heavier loads are transported on public roads at higher speeds. With the combination of higher-energy level and more rapid deceleration, brake systems with excellent heat dissipation characteristics are required. Wet multiple-disc brakes have similar multiple-disc construction, but operate in an oil bath. ABS is the next step in the development of a brake system of the tractor that brings an additional level of safety and control. In addition to the illustrations of development trends of the various components of the braking system of agricultural tractors and trailers, the aim of this paper is to describe the FE modelling of wet multiple-disc brakes and their brake performances.*
Key words: agricultural tractors; trailers; multiple-disc brakes; brake performances

1. INTRODUCTION

There is a tendency worldwide to improve tractor's transporting performance by increasing tractor speed. Faster, bigger, more powerful and more manoeuvrable machines are capable of developing ever higher speeds. Nevertheless, the increase of the agricultural vehicles' speed requires efficient braking system that should enable agricultural vehicles to keep the pace with the other fast vehicles participant in road traffic, taking into account traffic safety. Braking technology for the mega-machines of today and tomorrow needs to be equally efficient, low-maintenance, convenient and economical. Highly effective, oil-cooled multi servo disk brakes guarantee a solid, reliable braking performance.

Tractor standards include three basic types of standards: safety, performance and interoperability. There are seven different major Standard Development Organizations (SDOs) for the agricultural tractor industry: the Organization for Economic Co-operation and Development (OECD), International Organization for Standardization (ISO), International Electrotechnical Commission (IEC), Society of Automotive

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Engineers (SAE) International, American Society of Agricultural and Biological Engineers (ASABE), Association of Equipment Manufacturers – Equipment Manufacturers Institute (AEM-EMI), Nebraska Tractor Test Laboratories (NTTL) [1].

The European directive 76/432/EEC specifies the performance requirements for the braking systems of wheeled agricultural tractors with a maximum speed of up to 40 km/h (categories T1, T2 and T3). When the directive came under revision, tractors faster than 40 km/h (Category T5) and trailers & interchangeable towed machinery (category R&S), have come into the scope. Until a compromise has been found between European Commission/Member states/ industry categories, T5 and R&S vehicles fall under national type approval for braking. Braking on self-propelled agricultural machinery is also handled by national approvals. Regulation 167/2013 of the European parliament and of the Council of 5 February 2013 on the approval and market surveillance of agricultural and forestry vehicles add requirements and expand the scope to cover tractors, trailers, and towed equipment up to 60 km/h and above. Also in development is ISO 12933 Agricultural tractors - Safety and performance requirements for braking [2].

In North America, ANSI/ASAE S318 references ANSI/ASAE S365, Braking System Test Procedures and Braking Performance Criteria for Agricultural Field Equipment for braking requirements [3]. The scope of this standard includes both tractors and agricultural equipment. For a European designer of tractors marketed in North America, the minimum park brake performance requirement in this standard is particularly noteworthy. To paraphrase, the parking brake needs to hold the equivalent of 2.5 times the maximum weight rating for the tractor on an 18% slope [4]. This is more rigorous than the European equivalent of the maximum weight rating of a tractor on an 18% slope [5].

A summary of the minimum tractor braking performance requirements expressed as percentage efficiencies (i.e. braking effort as a percentage of the tractor's Design Gross Vehicle Weight (DGVW)) are included in Table 1 below. These will apply to both new and existing agricultural tractors from 1st January 2016.

Table 1 *Revised Agricultural Tractor Braking Standards*

Minimum Braking Performance Requirements for Agricultural Tractors	
Speed rating less than or equal to 40 km/h	Speed rating greater than 40 km/h
Service Brake (25%) Parking Brake (16%)	Service Brake (45%) Emergency Brake (22.5%) Parking Brake (16%)

A summary of the minimum trailer braking performance requirements, once again expressed as percentage efficiencies, are included in Table 2 below. Note that the figure quoted for the service brake performance is based on the weight transmitted to the road surface by the trailer axle(s) fitted with brakes, whereas the breakaway and parking brake performances quoted are based on the Design Gross Vehicle Weight (DGVW) of the trailer. These will apply from 1st January 2016.

Table 2 *Revised Agricultural Trailer Braking Standards*

Minimum Braking Performance Requirements for Agricultural Tractors	
Trailers with a speed rating less than or equal to 40km/h and a Design Gross Vehicle Weight (DGVW) exceeding 5,000kg.	Trailers with a speed rating greater than 40km/h and a Design Gross Vehicle Weight (DGVW) exceeding 3,500kg.
Service Brake (25%) Breakaway Brake (13.5%) Parking Brake (16%)	Service Brake (45%) Breakaway Brake (13.5%) Parking Brake (16%)

Furthermore all agricultural trailers which are manufactured from 1st January 2016 and are capable by design of being drawn at a speed exceeding 40km/h must be equipped with:

- pneumatic braking systems (including load sensing functionality which matches the service brake effort to the weight of the load being carried); and those capable of being drawn at a speed exceeding 60km/h must also be equipped with antilock braking systems (ABS).
- a breakaway brake capable of automatically stopping them should they become detached from the tractor while in motion.

Amendments to the Regulation of the division of motor vehicles, trailers and technical requirements for vehicles in traffic in Republic of Serbia of 22nd September 2014 brought: detailed definition of vehicles of type R-tractor trailer and type S-towed equipment, as well as the term-working equipment. It is also explained in more detail the term of braking coefficient, method and conditions used to measure it. The table that gives the prescribed minimum value of the braking coefficient is supplemented with the values for type S for working and auxiliary braking. Prescribed norms referring to the braking coefficient for vehicles of type T, i.e. R and S apply also to the measurement of deceleration vehicles' combination consisting of a tractor and tractor's trailer type R or S [6].

2. DEVELOPMENT OF TRACTORS AND TRAILERS' BRAKE SYSTEM

Braking performance of the vehicle is prescribed by technical requirements and is determined by deceleration (m/s^2) of the vehicle during braking. The tractor must be equipped with two independent braking systems (Figure 1). For normal operation and control of the braking system, the maximum physical force required from a man during the maximum braking deceleration is in the range from 200N to 490N.

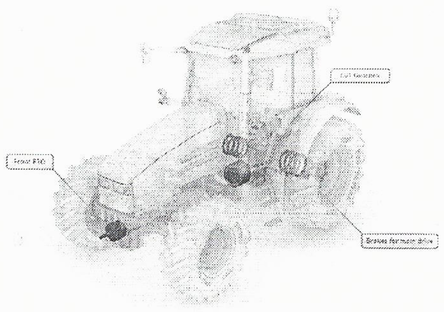


Fig.1 *Brakes for main drive*

The weight distribution and large rear tires of conventional tractors have enabled tractors to generate sufficient braking effort from their rear wheels alone; typically such tractors have no front brakes fitted. The move to 40 km/h tractors in Europe has coincided with the almost universal acceptance of front wheel assist driven axles. This has given manufacturers the opportunity to engage the front axle drive while braking. This technology has also been carried into the 50 km/h tractor models, with the addition of incorporating some form of disc brakes onto the front drive system to assist the braking effort.

In the case of hydrostatic transfer of the control force, the muscle force shall be transferred from the brake pedal to the master hydraulic cylinder, and then through the hydraulic installations to the individual braking elements, which are mounted on the driving wheels or some other elements with rotational motions (Figure 2). Usually, braking elements are mounted before the final transmission on the drive wheel for easier braking-stopping vehicles at lower rotational moment of inertia, and this is occurring at the moment of stopping of the tractor.

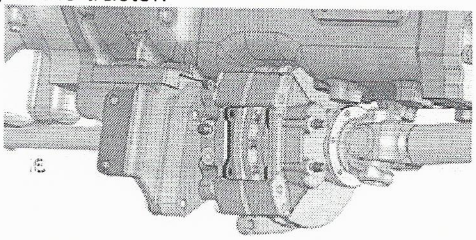


Fig. 2 *Drive shaft brake*

Multiple disc brakes consist of a plurality of braking plates, which are operating in the dry/oil condition with a large pressure force between the plates during braking. To reduce the wear of the brake lining, disc brake pads are immersed in oil, and they are protected from dirt, the circulation of the oil through a heat exchanger usually provides greater heat dissipation than can be had from direct air cooling and have steady braking effect and a long service period. Their downside is significant energy loss due to hydraulic friction between the linings and oil, especially in higher speeds and cold oil in the state when the brakes are not used, but the brake disc rotating with a certain speed.

Ball on ramp brakes (Figure 3) have a mechanism inside the axle however if they are hydraulically applied the actuation is usually accessible from outside which helps to reduce servicing costs. In order to make a ball ramp actuator non servo the actuator must be decoupled from the friction plates.

Fig. 3 *Ball on Ramp Brakes*

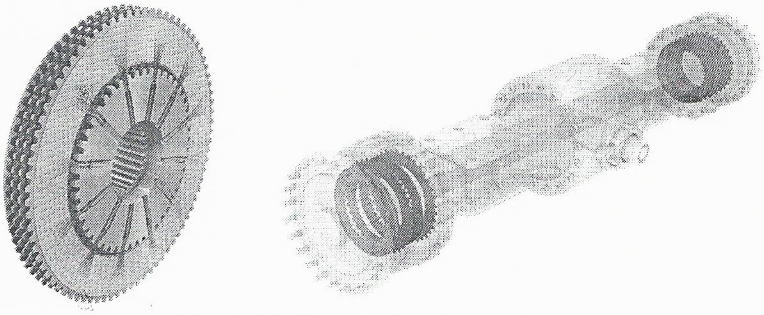
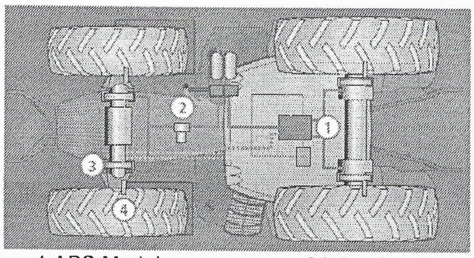


Fig. 4 *Multi-plate disc brake [7]*

Most modern multi-plate disc brakes (Figure 4) run in oil to transfer the heat away from the friction plates but that hasn't always been the case. The enclosed nature of the brake does require consideration of heat dissipation though. There are two fundamental types of multi-plate brakes, servo and non servo. The purpose of a multi plate disc brake is the same as the more conventional calliper. It has to retard, stop and hold the vehicle. The fundamental difference is that it is self contained and cooled by oil. Many vehicles using this type of brake have hub reduction gearing so it is common for oil immersed brakes to be inboard of this gearing and as such they run at five or six time wheel speed.

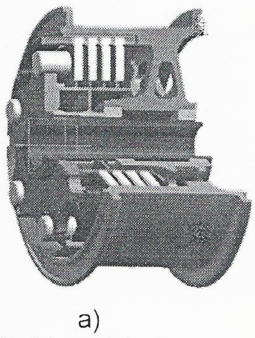
Uneven terrain and a huge amount of variation in traction conditions, even from wheel to wheel, means that an effective antilock braking system for tractors requires more advanced development. The ABS module (Figure 5) measures the speed on each individual wheel using four speed sensors. Since the wheels on tractors have a high inertia due to their size and weight, the ABS module also communicates with the tractor control unit. The control unit can then drive the affected wheel via the transmission, if opening the brake is not enough to maintain the required speed. Both front wheels are controlled together to maintain the stability of the tractor, even if there are different surfaces under each wheel. The rear wheels are controlled individually by the ABS module.



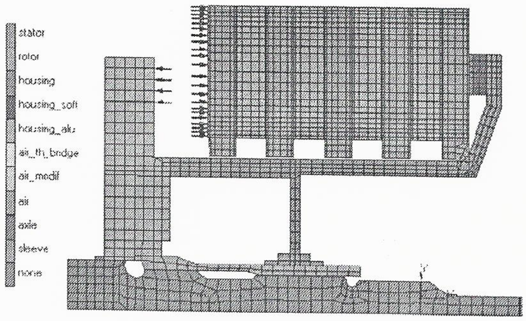
1 ABS Module 3 Wheel brake
2 Pressure limiting valve 4 Speed sensor

Fig. 5 *ABS – for the highest level of braking performance*

Influence of different mechanical and thermal properties of composite materials is easily obtained from FE analysis. In this sense FE simulation is a perfect tool for sensitivity analysis. Also the nonuniformities observed in the current results can serve as guidelines for the future to obtain the desired effect (Figure 6).



a)



b)

Fig. 6 *a) Solid model of a wheel brake assembly b)Mechanical load during brake action*

3. CONCLUSION

Adoption of the upcoming European legislation in the field of agricultural tractor and trailer will place new demands on manufacturers of agricultural tractors, trailers and machinery in terms of braking systems. An increase number of tractors with speeds over 60 km/h participate in traffic on highways. Therefore, they must comply with the braking performance of other traffic participants. This led to the development of new generation of efficient wet multi plate brakes, combined tractor's hydro-pneumatic braking systems that are compatible with trailer's pneumatic braking system, braking combined with steering system that increase tractor manoeuvrability, ABS braking system, etc.

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