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DEVELOPMENT OF TRACTORS AND TRAILERS IN ACCORDANCE WITH THE REQUIREMENTS OF LEGAL REGULATIONS

Abstract: *Operation tasks of tractors and trailers in agriculture have changed considerably over the last decade. Today on the roads of Europe and the United States are tractors whose speed exceeds 50 km/h, even when fully loaded, which raises important issue of the effective stopping i.e. the quality of the braking system. Tractor trailers must correspond to the tractors with respect to size and weight, but must be capable of moving at speeds of towing vehicle. Their braking must be synchronized with the tractor and must not affect the deterioration of the operation quality of tractor-trailer combination. Also important is their good maintenance to avoid problems with the braking of the towing vehicle. In order to address these issues, revised braking requirements will apply to all agricultural tractors and their trailers (both new and existing) from 1 January 2016. They will also apply to equipment such as slurry tankers, fertiliser or manure spreaders, grain chaser bins and so on.*

Keywords: *tractors, trailers, brake system, legal, requirements*

1. INTRODUCTION

The basic technology of agricultural machines has changed little over the last century. Though modern combine harvesters and planters may do a better job than their predecessors, the combine of today cuts, threshes, and separates grain in essentially the same way earlier versions had done. However, technology is changing the way that humans operate the machines, as computer monitoring systems, GPS locators, and self-steer programs allow the most advanced tractors and implements to be more precise and less wasteful in the use of fuel, seed, or fertilizer. In the foreseeable future, some agricultural machines may be made capable of driving themselves, using GPS maps and electronic sensors.

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. Only the future will show whether the achievement of 50 km/h speeds signals an upper limit. 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.

The standards associated with tractors are much more complicated than one outside of the standard's profession might expect. 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 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). This directive was last modified in 1996. 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. The historical national differences within the EU, especially concerning trailer braking, require a lot of effort because the process of harmonization is complicated [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. Again, this difference can be traced back to the cultural practice and requirement for the use of chocks in Europe with no like requirement in North America. Per ANSI/ASAE S365, a trailer may weigh up to 1.5 times the weight of the tractor before trailer brakes are required, hence the parking brake requirement [5].

2. NEW BRAKING LEGISLATION

As agricultural tractor size and speeds have increased during recent years, heavier loads are transported on public roads at higher speeds [6]. Due to the increased speed of tractors, their braking system has been enhanced. In view of the road safety, the braking systems of agricultural vehicles must meet a number of requirements for, among other things, braking efficiency, the follow-up action during slow braking, and a high speed of action during sudden braking.

The operation of a high speed modern agricultural tractor with high-efficiency brakes coupled with a low braking efficiency trailer will lead to the accelerated wear and premature damage of the trailer's braking system and, on the other hand, cause overloading, rapid wear and possible damage of the tractor's braking system [7].

Tractors that travel below 40km/h must have a braking efficiency of 25%. If a tractor is to travel faster than 40km/h it must comply with EEC Directive 71/320. The regulations sets out that the vehicles must have service, secondary and parking brakes and a braking efficiency of at least 45%. When a trailer is being used further complications are added. The regulations state that the trailer brakes must be able to be applied independently should the tractor's brakes fail. A further stipulation is that the trailer's brakes must be applied automatically if the tractor and trailer become decoupled. The Directive does not stipulate that air-brakes are necessary; however most of the aforementioned requirements can be met by use of air brakes. Most tractor and trailer combinations do not comply with this regulation, confirmation can be provided by the manufacturer.

Tractor-trailer operation at 50 km/h increases the energy dissipation requirement placed upon the vehicle braking systems by over 140% (an approx. 2.5 times increase) (see Figure 1). Whilst modern tractor systems have usually been engineered to accommodate this increase, trailer braking systems currently in-service frequently have not: a situation accentuated by the fact that agricultural trailers are usually expected to have a frontline service life of 15 - 20 years plus. A trailer can easily outlive two or more generations of tractor, but only if the running gear and braking systems are adequately specified in the first instance. If the trailer braking system is undersized, the initial consequence is accelerated wear and premature failure of the trailer braking system, followed by overloading, rapid wear and eventual failure of tractor braking system. This has become an increasing problem within the EU in recent years, as demonstrated by the proportion of tractor braking system failures during vehicle warranty periods arising from these regions [7].

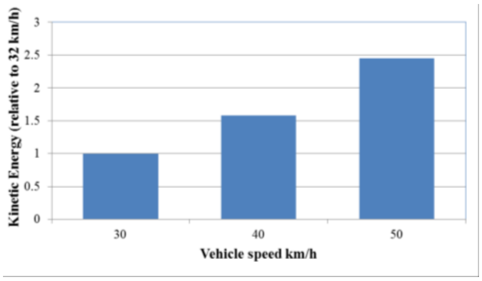


Figure 1 *- Disproportionate effect of increasing speed upon vehicle kinetic energy*

2.1 Revised Requirements for Agricultural Tractors

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 Applicable from 1st January 2016.*

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

2.2 Revised Requirements for Agricultural Trailers

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 Applicable from 1st January 2016.*

Minimum Braking Performance Requirements for Agricultural Trailers	
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.

However agricultural trailers manufactured prior to 1st January 2016 (provided they are incapable by design of being drawn at a speed exceeding 40km/h) may alternatively be fitted with a secondary coupling consisting of a chain or wire rope.

Agricultural trailers and interchangeable towed equipment manufactured prior to 1st January 2016 which are capable by design of being drawn at a speed exceeding 40km/h and which are not fitted with a breakaway brake have until 1st January 2016 to achieve compliance.

2.3 Revised Requirements in Serbia

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 [8,9].

3. DEVELOPMENT OF TRACTORS AND TRAILERS' BRAKE SYSTEM

Fundamentally, brakes serve the function of reducing vehicle kinetic energy by conversion into heat energy. As a function of the square of vehicle speed, kinetic energy increases rapidly. For example, a tractor traveling at 80 km/h dissipates approximately seven times the energy for braking than a tractor traveling at 30 km/h. This situation is exacerbated by the legal requirement for faster moving vehicles to decelerate at higher rates. For example, 30 km/h tractors have historically been required to have braking systems capable of deceleration at 2.8 m/s^2. When tractors reach a speed of 50 km/h, they are required to decelerate at a rate of 5.0 m/s^2, which is the same as the trucking industry. With the combination of higher energy level and more rapid deceleration, brake systems with excellent heat dissipation characteristics are required. Conventional tractors have normally relied on either dry or oil immersed disc brakes incorporated within the tractor rear axle. The oil used is common with that used for axle lubrication, gearbox lubrication and as an external hydraulic oil supply to implements. Contamination of this oil with brake lining debris can lead to serious functional problems within the tractor hydraulic or transmission systems. Breakdown of oil lubrication properties can also occur if the oil is subjected to high temperatures leading to impaired durability of components.

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.

According to the ANSI/ASAE Standard, S365.8, "Braking System Test Procedures and Braking Performance Criteria for Agricultural Field Equipment," the braking system requirements for agricultural trailers and towed agricultural machines are broken into two areas: one concerning towed equipment without brakes and the second with brakes:

1. For towed equipment WITHOUT brakes, the following information shall be provided: Do not tow equipment that does not have brakes:

- at speeds over 32 km/h, or
- at speeds above that recommended by the manufacturer; or
- that, when fully loaded, has a mass (weight) over 1.5 t and more than 1.5 times the mass (weight) of the towing unit.

2. For towed equipment WITH brakes, the following information shall be provided: Do not tow equipment that has brakes:

- at speeds over 50 km/h, or
- at speeds above that recommended by the manufacturer, or
- that, when fully loaded, has a mass (weight) more than 4.5 times the mass (weight) of the towing unit.
- at speeds over 40 km/h, when fully loaded has a mass (weight) more than 3.0 times the mass (weight) of the towing unit [10].

Until recently, it has been the general opinion that the standard tractor concept was only suitable for an engine power of up to 220 kW and that more power was only appropriate for tracklaying or articulated steer tractors. However, the leading suppliers of top power class tractors have increased engine power again. Fendt is realizing the first standard tractor which is able to drive 60 km/h. For this purpose, the brakes were adapted (dual circuit brakes with one independent brake for each wheel). Depending on the driving speed, the swing compensation of the single-wheel suspended front axle is reduced, which leads to better ride stability [11].

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 (service and parking brake). 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.

Steadily diminishing braking, reliable operation, low wear of the brake elements, and insensitivity to dirt and water are also required from the braking device. In the case of mechanical control, the muscle force is transferred from the brake pedal or control lever through a mechanism directly to the braking elements of the braking device. Due to limitation of the compression force on the brake pedal, thus also the mechanical friction of the brake linings, the mechanical brake control is used only in handbrake and in service brake for smaller tractors. The braking command on the tractor is allowed to be laterally divided, whereby each brakes pedal corresponding to the brake to one side of the vehicle. On the Figure 2, the control pedals are presented in a connected and disconnected position.

Figure 2 *- Connected and disconnected command of tractor's brake*

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. 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. The control braking force on the brake pedal can be increased by using a servo hydraulic device, which increases the efficiency of braking and reduces the need of the physical force on the brake pedal.

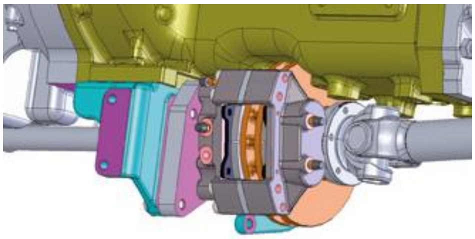


Figure 3 *- Drive shaft brake*

Some manufacturers have developed a solution of drive shaft brake acting on Cardan shaft, which has been proven optimal particularly as safety brakes for safe parked on a slope (Figure 3). The advantage of this system: Due to the security lock the brake pedal of the service brake is mechanically locked.

Brakes are classified depending on the brake components: drum and disc, brake elements may be dry or immersed in oil. Dry braking elements have a large friction coefficient and a small contact surface and the accessibility, and ease to repair. Advantages of wet brake linings are in good heat dissipation and low wear of brake linings.

Disc brakes are used on tractors as a service brake, normally for braking of the front wheels of the tractor, and they are mounted on a shaft for the transmission of torque. They have wider use in the personal and commercial vehicles, Figure 4 (a). Multiple disc brakes consist of a plurality of braking plates, which are operating in the dry condition with a large pressure force between the plates during braking, Figure 4 (b). Pressure force is transferred due to changes in the position of balls, placed between the plates - the Girling system, Figure 4 (c). When the brake is not applied, there is a small energy losses due to friction and is protected from impurities. To reduce the wear of the brake lining, disc brake pads are immersed in oil, brake control is hydrostatic, and they are protected from dirt, and have steady braking effect and a long service period, Figure 4 (d). 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.

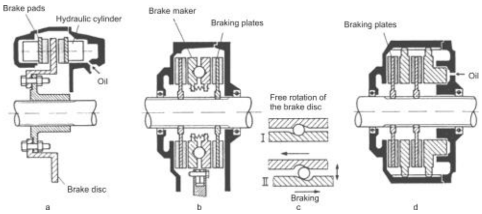


***Figure 4** - Different constructions of disc brakes* [12]

Ball on ramp brakes (Figure 5) 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.

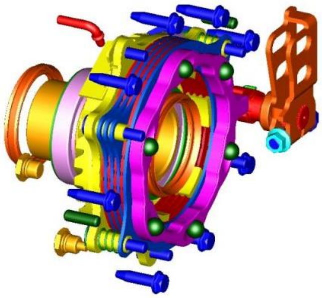


***Figure 5** - Ball on Ramp Brakes*

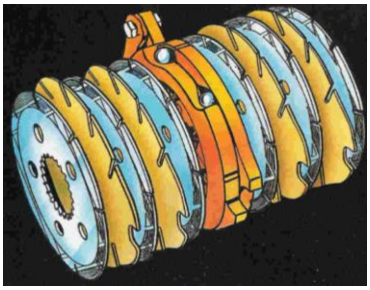


***Figure 6** - Multi-plate disc brake*

Most modern multi-plate disc brakes (Figure 6) 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. The braking faces are between a number of interleaved friction discs and counter plates alternately keyed to the housing or splined to a driveshaft. The plates are clamped together to produce a braking torque either by an annular piston which is coaxial with the driveshaft or by a ball and ramp mechanism. 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.

There are four basic types of friction materials available each with their own pros and cons, sintered, paper, graphitic, carbon (Figure 7).

***Figure 7** - Basic types of friction materials*

Sintered bronze is made by sintering a blend of powders into a porous matrix on a steel carrier plate. It is a tough durable material well able to live with overheating. On the downside it has a low dynamic friction and a high static/dynamic friction ratio which can cause chatter noise. Paper frictions materials are so called because of the manufacturing process as much as the material itself. They contain a range of fibres and friction modifiers which are then saturated in resins. The resulting material is soft and easily damaged. Paper materials have a high dynamic friction level and a low static/dynamic friction ratio which gives them well torque capacity and low noise however their energy capacity tends to be low. Graphitic materials are moulded compositions of graphite and resin binders. The have good thermal capacities which make them durable however they have a moderate static/dynamic friction ratio which may make them noisy. Carbon linings give stable friction, high load and low wear but are very expensive as such they are rarely used.

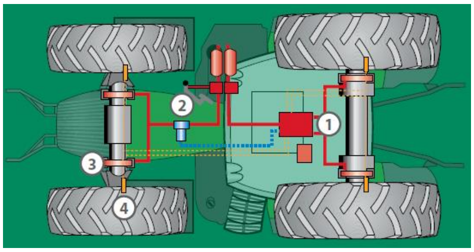
Grooves are either machined or moulded into the friction material to aid oil flow and thus cooling. Numerous patterns exist and each friction plate manufacturer has his favourite however the following points should be born in mind. The oil must be part of the cooling process.

Putting the servo mechanism directly at the brake allows the rest of the system to run at reduced stress, for example the hydraulic pressure could be reduced to about 25% of that used in an actuator boosted system.

Figure 8 *- Multi-plate disc brakes with servo mechanism*

Magnetorheological brakes are type of braking systems which utilize magnetorheological fluid as a medium in brake torque transfer. These systems have possibility of precisely handling the braking force electrically, do not require special adjustments, neither periodical maintenance [13].

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 measures the speed on each individual wheel using four speed sensors. If the speed on one wheel is too slow, the ABS automatically opens the corresponding brake to prevent the wheel from locking. Since the wheels on tractors have a high inertia due to their size and weight, the ABS module also commu- nicates with the tractor control unit. The control unit can then drive the affected wheel via the Vario 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

Figure 9 *- ABS – for the highest level of braking performance*

New and smart application of ABS technology to tractors, which not only offers confident stopping power with increased safety, but also increases tractor manoeuvrability and improves safety when operating on steep hills is developed in CNH Industrial New Holland. ABS SuperSteer™ uses ABS technology to manage each wheel's brake individually.

Using a single foot pedal, the ABS SuperSteer™ allows the tractor to be steered by the brakes. Two orange pedal extensions either side of a single pedal replace the conventional, independent two-pedal arrangement. At low speed, this provides the driver with the same single-wheel steering as a conventional tractor, but automatically disables at higher speeds to prevent accidental application.

Figure 10 - New Holland's ABS SuperSteer brake-assisted steering will be operated by extensions to the single brake pedal [14]

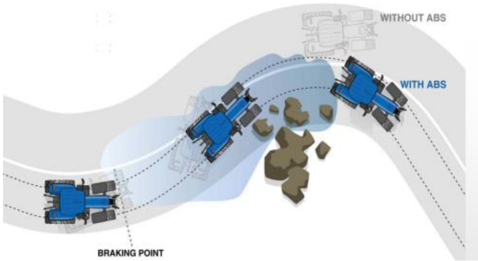


Figure 11 - Improve manoeuvrability with ABS [14]

The ABS SuperSteer™ function includes tyre slip control and automatic coupling with the steering angle. This allows the tractor to perform tight turning manoeuvres without driver intervention on brakes by pivoting on a braked rear wheel, reducing the turning circle to that of a tractor fitted with a SuperSteer™ front axle. A driver-selectable amount of slip on the pivoting wheel is allowed to prevent soil damage.

4. 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. Future EU tractor-trailer braking legislation is likely to require significantly greater performance. This can be achieved without undue difficulty or excessive cost, but there is a vital need to raise user awareness and understanding of trailer and trailed appliance braking system specification and selection, to minimise future performance shortfalls.

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