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INTELLIGENT CONTROL OF VEHICLE COMBINATION BRAKING COMPATIBILITY

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ABSTRACT - The braking performance co-ordination between the tractor and its trailer is considered as the most important aspect of active safety of commercial vehicles. A need to improve compatibility behaviour of vehicle combinations leads to better control of the most relevant compatibility disturbing factors and an improved EBS braking forces management would certainly enable to reach the given task. The braking force management strategy between tractor/trailer combinations should be considered as a critical point for further braking compatibility behaviour improving and active safety in general. EBS offers possibilities for further innovative solutions for controlling of tractor/trailer braking systems operation and braking compatibility improving. EBS ability for electronically controlling of the index pressures between the proportional relay valve (front axle), axle modulator (rear axle) and trailer control valve has been used in this paper for introducing a new adaptive control strategy of the vehicle combination braking. This paper deals with adaptive control of the tractor/semi-trailer braking systems performance, based on artificial intelligence, as an innovative approach to manage of the tractor/semi-trailer braking forces to be synchronized at all times.

INTRODUCTION

It is expected today that operation of modern commercial vehicles is safe, efficient, comfortable, and ecologically compatible (1). A tractor/trailer combination is considered well synchronized when differences between brake forces of the motor vehicle and the trailer (semi-trailer) are kept to the absolute minimum and when dynamic retardation of the respective axles in a tractor/trailer combination is identical (2,3). Due to different design and load characteristics of these vehicles, different performance of their braking system transmissions, and in particular different wheel brakes and their tribological behaviour are the main reasons for a vehicle combination not to be "compatible", or balanced during braking. Inappropriate braking of these vehicles may cause heavy accidents due to (i) relatively longer stopping distances, (ii) higher energy output of brakes, (iii) tendency towards jack-knifing, etc.

There is no doubt that EBS not only considerably enhances both vehicle and road safety, especially by reducing the stopping distance and improving braking stability (4,5) but also represent a major improvement in terms of economy and driving comfort by means of: (i) shorter response time, (ii) reduction of the number of individuals component, (iii) synchronization of brake lining wear on the individual vehicle axles, and (iv) a considerable improvement in the compatibility between the towing vehicle and its trailer (1,6).

However, EBS offers possibilities for further innovative solutions for controlling of braking systems performance of the vehicle combination. A need to improve braking compatibility behaviour of vehicle combinations leads to better control of the most relevant disturbing factors. An improved EBS braking forces management would certainly enable to reach the given task. The braking force management strategy between tractor/trailer combinations should be considered as a critical point for further braking compatibility behaviour improving and active safety in general.

The compatibility issue of heavy vehicle combinations is covered by means of requirements prescribed in Annex 10 of ECE Reg. 13 (or respective EC Directive 71/320/EEC) (7). The adhesion utilization demonstrates compatibility behaviour. In the case, that the line showing relation between control line pressure at the vehicle combination coupling head and the vehicle's braking rate is within the corridor prescribed by these diagrams, braking systems of both combination components will produce balanced partial decelerations. In such a way, compatibility of a vehicle combination will be considered as acceptable. However, it is evident from fig.1 that even in the case when achieved braking rate lies in the middle of the prescribed bands, due to different upper and lower limits for the specific tractor/semi-trailer combination, braking compatibility is not provided i.e. partial decelerations are not the same.

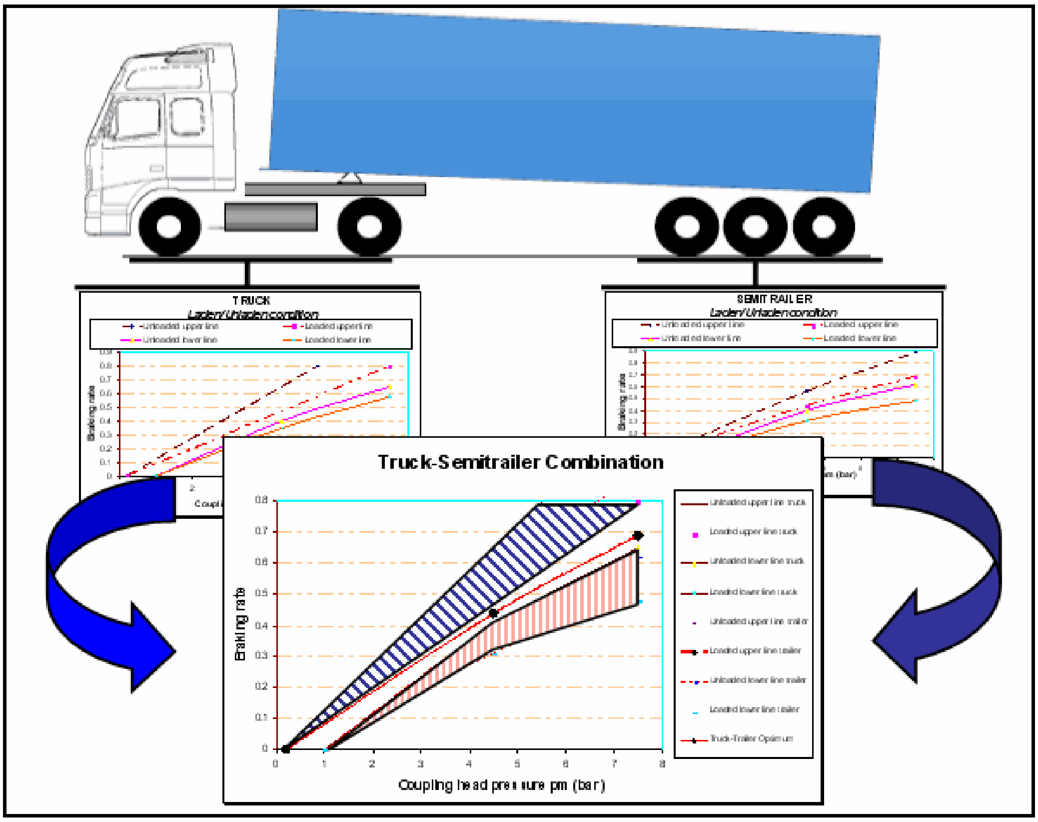

Fig. 1. Vehicle combination compatibility requirements

Instead of trying to achieve a braking rate somewhere in the prescribed corridors for the tractor and trailer, the braking systems of tractor and trailer could be forced to achieve the predefined (target) braking rates values versus control line pressures. The target braking rates line can be differently set up depending on the vehicle combination operating conditions. From fig. 1 can be seen how the unique target line of the braking rates changing can be established to satisfy braking compatibility requirements for both laden and unladen conditions of the vehicle combination. It means that the specific braking rate, versus control line pressure selected by driver, is known in advance and the each braking system of the vehicle combination has to be control on the manner to provide the same braking rates related to the target function.

EBS ability for electronically monitoring and controlling of the index pressures between the proportional relay valve (front axle), axle modulator (rear axle) and trailer control valve has been used in this paper for introducing a new adaptive control strategy of the vehicle combination braking forces. The adaptive control of the tractor/semi-trailer braking systems performance, as an innovative approach to manage of the tractor/semi-trailer braking forces to be synchronized at all times, is based on monitoring, identification, and modelling of the tractor/semi-trailer (trailer) braking systems function. The tractor/trailer braking systems functioning could be modelled by establishing relationship between partial decelerations of the tractor/semi-trailer (trailer) combination versus influencing factors such as: (i) vehicle combination speed, (ii) intended deceleration by the driver, and (iii) the load carried at the time. Here proposed advanced control of the index pressures between tractor and its semi-trailer (trailer) would be realized by artificial intelligence based models of the vehicle combination braking systems functioning versus different operating regimes.

EBS ADAPTIVE CONTROL STRATEGY

The brake signal transmitter of EBS is used to generate electrical and pneumatic signals according to driver demands. The signal received form the brake signal transmitter determines the vehicle intended retardation. Together with the wheel speed measured by the wheel speed sensors, the intended retardation is the input signal for EBS control, which uses these readings to establish the index pressure values for the tractor's front and rear axel, and the trailer control valve. Depending on the given index of deceleration and the load carried, the braking pressures are computed individually for both the towing vehicle and its trailer.

If the decelerations of the towing vehicle and its trailer lie in the middle of the prescribed bands, it is considered by control unit of EBS as no coupling force occurs. If the decelerations deviate from the middle bands position, the motor vehicle ECU will perceive this by means of retardation control portion of the program and will adjust the actuating pressures in the braking systems of vehicle combination. This is a critical point where EBS controlling function abilities could be improved regarding the control of tractor/semi-trailer compatibility behaviour.

Therefore, it can be concluded that EBS are trying to act correctively against some disturbances, and that is why further improvement of EBS control strategy related to coupling force control is proposed in this paper. This improvement is related to introduction of the new integrated EBS control strategy consisted by monitoring, identification, modelling, and based on that adaptive controlling of the tractor/trailer braking systems performance. Braking compatibility issue with EBS adaptive control of the tractor/trailer braking systems performance, based on models of their real operation in different driving conditions, would be solved much more efficient. Furthermore, this control strategy providing that the tractor/semi-trailer (trailer) braking systems at any time and under any usage conditions offers the maximum of its actual capabilities and needs only software changes of the retardation control program.

From fig. 2 can be seen a new strategy (strategy I) for controlling of the vehicle combination braking compatibility. This strategy is based on establishing the unique target function or braking rates line versus coupling head pressure for both laden and unladen conditions of the vehicle combination. It is evident from fig. 2, this target function, corresponding to the upper limit of the semi-trailer in laden condition, is used for controlling the both braking systems (tractor and its semi-trailer in this case) at any load conditions. The upper limit of the semi-trailer in laden condition is chosen as a solution satisfying both load states and at the same time offers the maximum possible braking performance. Furthermore, this strategy including three different controls range: (i) wear control range, (ii) normal braking range, and (iii) panic control range.

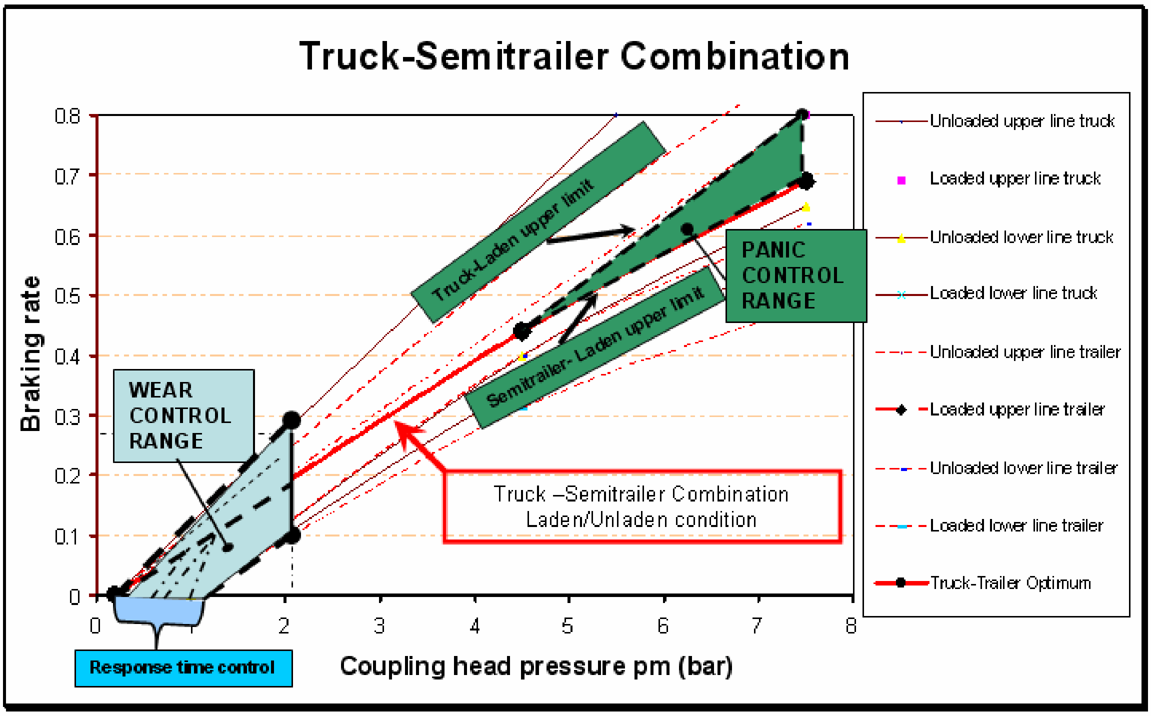

Fig. 2. Braking compatibility control of truck/semi-trailer combination -Strategy I

In the wear control range, for the pressure values not more than two bars, the wear balance of the brakes friction linings of the tractor and semi-trailer will be achieved by selecting of the appropriate pressure line applications of brakes, on the each axle of the vehicle combination, together with response time controlling between tractor and semi-trailer. In this range, the set up target function would not be considered because partial decelerations of the vehicle combination would be allowed to be changed in the marked wear control range.

During normal braking, the braking systems functioning of vehicle combination will be forced to fulfil predefined target function. According to fig. 2, the index pressures selected by control module need to be computed on such way to provide identical partial decelerations of vehicle combination that are known in advance (target function) for the specific operation condition (vehicle combination speed, wanted deceleration by driver) irrespective of the load state. Computation of the index pressure values for the front and rear axle of towing vehicle and for axles of semi-trailer (trailer) would be based on the neural model of the each braking system behaviour. Strategy for normal control braking can be changed according to acceleration of the brake signal transmitter in the case of panic braking. Here proposed vehicle combination braking strategy is able to recognize panic situation and to change the target function of the tractor braking system operation (see fig. 2).

In the panic situation the both braking systems (tractor and semi-trailer) will be forced to offer the maximum of its performance because the target function of the tractor will be changed from the upper limit of the semi trailer (laden condition) to the upper limit of tractor (laden condition). According to that, the index pressure values for the towing vehicle's axles would be adjusted to the new (panic) braking rate function. The semi-trailer braking system performance would be controlled according to previously set up target function on the upper limit of the semi-trailer for laden condition. Furthermore, the response time of the both braking systems will be also adjusted simultaneously with changing of the tractor braking strategy.

The main advantage of this braking strategy is only one target function for both load conditions based on which the tractor/semi-trailer braking systems performance would be controlled. Furthermore, the control of braking systems performance is based on laden condition of vehicle combination because in laden condition consequences of possible accidents are much more dangerous. Taking into consideration that laden condition of vehicle combination has been taken for the target function determination, in unladen condition the tractor/semi-trailer braking systems would not be allowed to offer its maximum capabilities regarding the prescribed limits. In order to provide the maximum capabilities of the tractor/semi-trailer braking systems in both load conditions the new strategy (strategy II) could be introduced, see fig. 3.

Previously explained strategy, based on the laden condition of the semi-trailer, is again kept for the braking of vehicle combination under maximum allowed load (see fig. 3). The braking strategy for the tractor/semi-trailer braking behaviour for unladen condition has been changed. Instead of only one target function for controlling of the braking systems of vehicle combination, the two target functions have been introduced (fig. 3). Similar to the target function of laden vehicle combination, a new target function of unladen vehicle combination corresponds to the semi-trailer upper limit for unladen condition.

The strategy II also providing the three different control ranges: (i) wear control range, (ii) normal braking range, and (iii) panic control range. The wear control range remains the same as it was explained for the strategy I. In the normal braking control range there are at least two different target functions depending of the load of vehicle combination. It means that new target functions could be introduced for the specific partial loads of the vehicle combination. It is possible because control module receiving information about tractor/semi-trailer load from the axle load sensors of both vehicles in combination.

During normal braking, the braking systems performance i.e. the index of pressures for each axle of vehicle combination will be adjusted according to intended retardation selected by driver, vehicle combination speed (speed sensors), and axles load (axle load sensors). Based on information received from the axle load sensors of vehicle combination the control module making decision related to the strategy that would be used for the tractor/semi-trailer braking controlling.

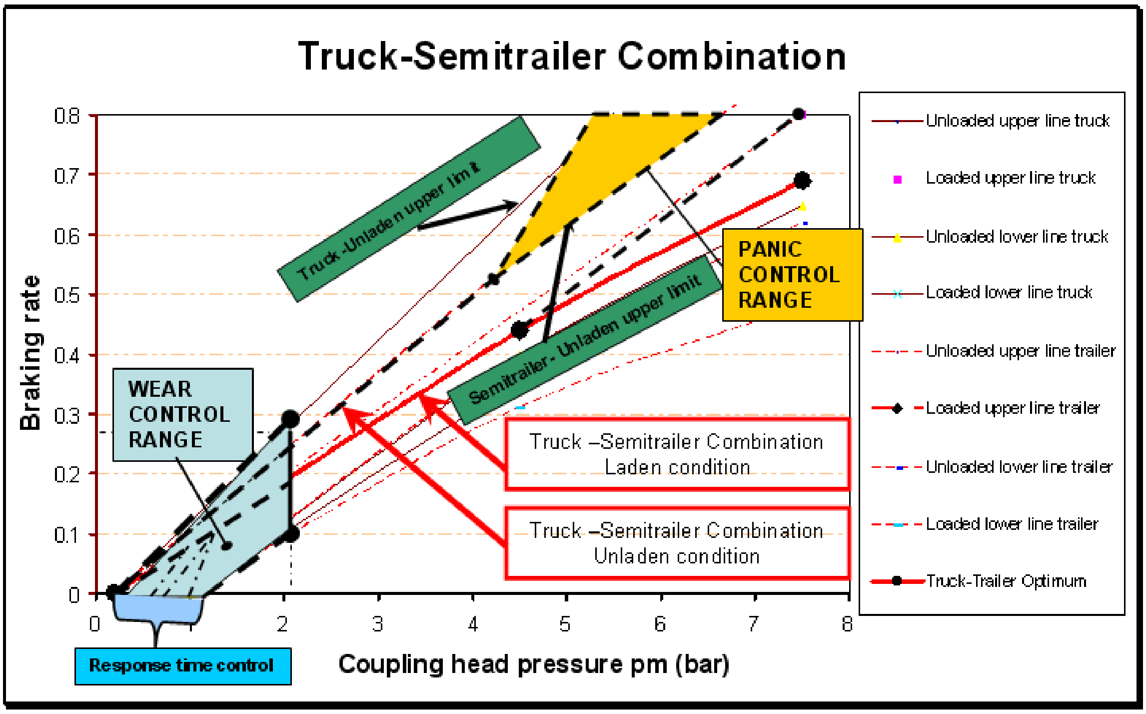

Fig. 3. Braking compatibility control of truck/semi-trailer combination -Strategy II

In the case of panic braking of the vehicle combination (unladen condition), the strategy for normal braking could be changed again. The panic target function in unladen condition of the vehicle combination is different from that used for normal braking situation. During panic braking a target function of normal braking is additionally corrected in the area of high pressure activations on the way that the tractor's braking system performance are forced to the its upper limit in unladen condition (see fig. 3). Furthermore, the target function of the both braking systems of vehicle combination in laden and unladen condition can be selected in panic situation on the way that the point of transition form normal target function to panic target function to be realized immediately after wear control range (fig. 2 and 3). Consequently, the braking systems of the both vehicles in combination would be offering its maximum performance that is more than important in the case of panic braking.

INTELLIGENT CONTROL OF BRAKING COMPATIBILITY

It has been explained that electronically controlled braking systems were offered to resolve some of the problems that may not be settled down by means of traditional pneumatic transmission braking systems. However, from the point of view of efficiency of such system, control transmission function has been improved so far, but braking forces management could be further improved. Therefore, all possible advantages of application of such sophisticated system were not yet been performed, but it seems these may be better used to control the braking compatibility behaviour of vehicle combinations. That is why EBS adaptive control function has been introduced as a new intelligent solution for the compatibility problem resolving.

Implementation, here proposed, intelligent control strategies of the tractor/trailer braking systems function could be done by artificial intelligence technology based on neural network control. The neural network control has great potential since artificial neural network are built on a firm mathematical foundation that includes versatile and well-understood mathematical tools (8-14). That is why in this paper artificial neural networks are used as one of the key elements in the design of controllers supposed to control tractor/semi-trailer braking compatibility behaviour according to developed neural model of the braking system functioning.

There are typically two steps involved when using neural networks for controlling: (i) system identification and (ii) control design (7). In the system identification stage, neural network model of the braking system function would be developed. In the control design stage, the developed neural network models of the braking systems would be used for the braking systems controller designing. The neural model of the braking system functioning (tractor or semi-trailer) serves to predict future behaviour of braking system versus different operating regimes including the input signal from the driver. On the other hand, the braking system controller based its function on this predictive model in order to select control input at every sampling instant using the updated information from the monitored braking system variables.

From fig. 4 it can be seen the basic principle of intelligent control of braking system functioning towing vehicle or its trailer. Therefore, a neural network models of the braking systems functioning of the tractor and semi-trailer needs to be developed. The neural model development of the each braking systems operation in vehicle combination implicates establishing functional relationship between input and output variables. It was mentioned that input variables are related to vehicle combination speeds, intended decelerations by the driver, and the load carried at the time and actual decelerations of the tractor and semi-trailer as an output variables. That is why, there would be two neural models of braking systems functioning and two separate neural network controller for the tractor and semi-trailer (trailer).

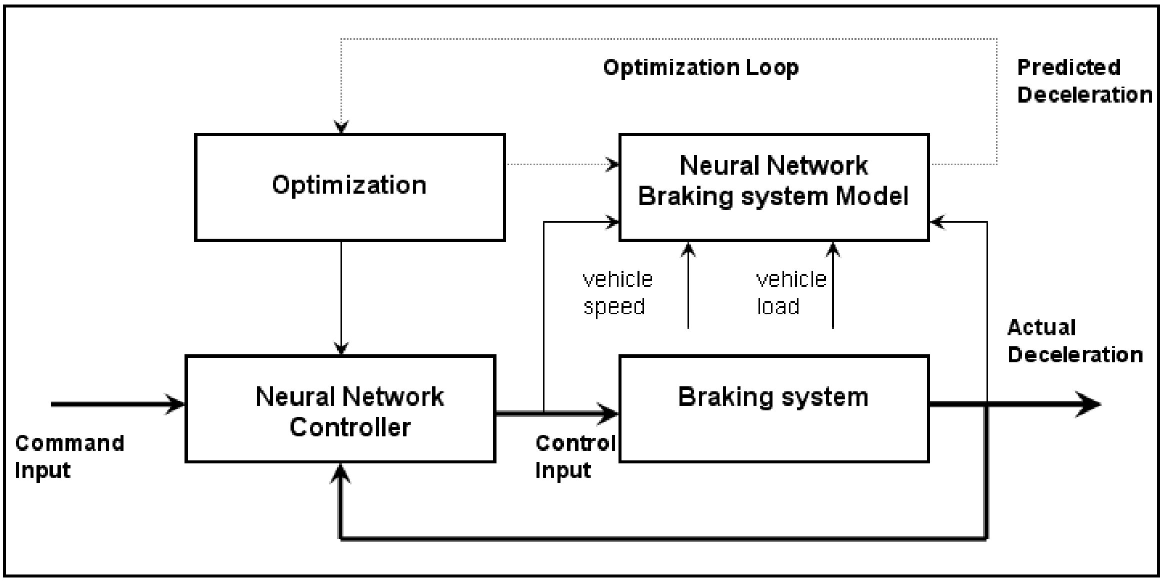

Fig. 4. Intelligent Control of braking system function

The modelling of the braking system function is based on its monitoring (it is possible with EBS now a day) and using of monitoring variables (driver deceleration demands, the index pressures, actual load carried by axle load sensor, vehicle combination speed by speed sensors, actual deceleration by speed sensors) for establishing input/output relationship. According to adopted strategy for the braking systems controlling, the basic precondition is related to establishing of the upper and lower limits for the both load state (laden and unladen). As it was explained in (7), the upper and lower limits of the tractor/semi-trailer combination depend on mass of vehicle, its wheelbase, and height of centre of gravity. That is why, it is important that intelligent braking system automatically recognize these vehicle's characteristics. It can be done using information from wheel speed sensors (4). Therefore, not only driver deceleration demands (by brake signal transmitter), the index pressures, actual load carried (by axle load sensor), vehicle combination speed and actual deceleration (by speed sensors) but also wheelbase and height of centre of gravity of vehicle can be calculated by wheel speed sensor, see fig. 5. Based on this information, the target function or braking strategy can be selected according to the actual braking situation initiated by the driver or by ESP system and tractor/semi-trailer (trailer) load conditions. Moreover, above explained intelligent control of vehicle combination braking offers possibilities for further integration with ESP.

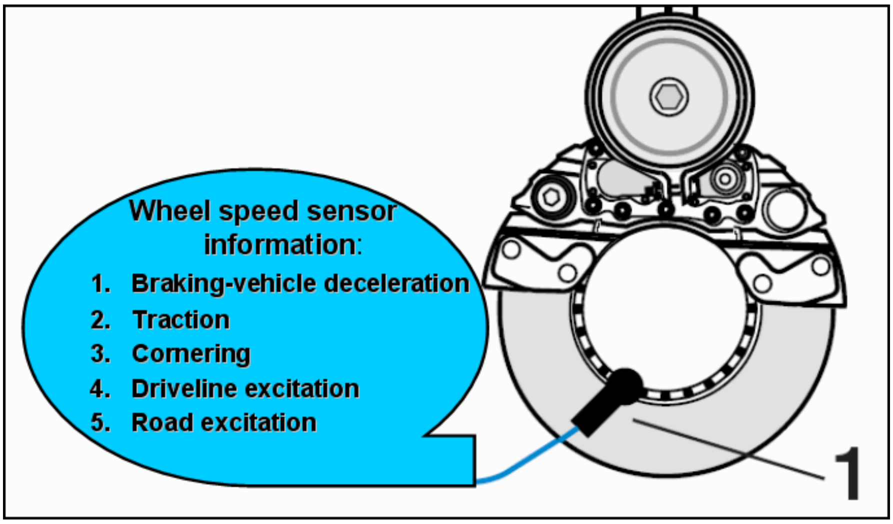

Fig. 5. Wheel speed sensor information

Therefore, any braking system action would be used for modelling i.e. neural network training in order to establish functional relationship between aforementioned inputs and outputs. After certain number of brakes applications, artificial neural network would be able to make prediction related to the braking systems performance (decelerations) versus actual operating conditions (selected the index of pressure by EBS, vehicle speed measured by speed sensors, and load carried at that time measured by axle load sensors). The benefit of this approach is that this prediction can be constantly evaluated and eventually corrected by neural network controller according to the real deceleration values for different disturbing influences (changes of the friction coefficient for different operation conditions, for instance).

The result of modelling of the tractor/semi-trailer braking systems functioning is shown on fig. 6. Form this figure can be seen real tractor and semi-trailer braking systems performance (unladen vehicle combination) and predicted ones obtained by neural network modelling. It is obvious that real tractor/semi-trailer braking performance (braking rates), for the specific usage conditions, deviate not only from the middle position of prescribed bands (unladen condition) but also deviate below lower limits specified for the tractor and semi-trailer. That is why, existence of the neural models of the braking systems operation (see fig. 6.) providing possibilities for their intelligent controlling. Based on the models of the tractor/semi-trailer braking behaviour, according to fig. 4, the neural network controller is able to make selection of control input (the index pressure values) for the front and rear axle of tractor and semi trailer's axles on such way to provide that partial decelerations of vehicle combination corresponding to the actual target function. Trained neural network continually adapting the model of braking system function and for the instantaneously vehicle combination driving condition suggesting the control inputs (the index of pressure) versus command inputs imposed by the driver.

Therefore, "quality" of the adaptive models of the braking systems functioning, versus driver commands and real braking system performance, is constantly checked by the controller and eventually corrected because of disturbing factors. During braking, the neural models of the braking systems operation are being evaluated by receiving information about real deceleration values, versus selected control input and vehicle operation condition.

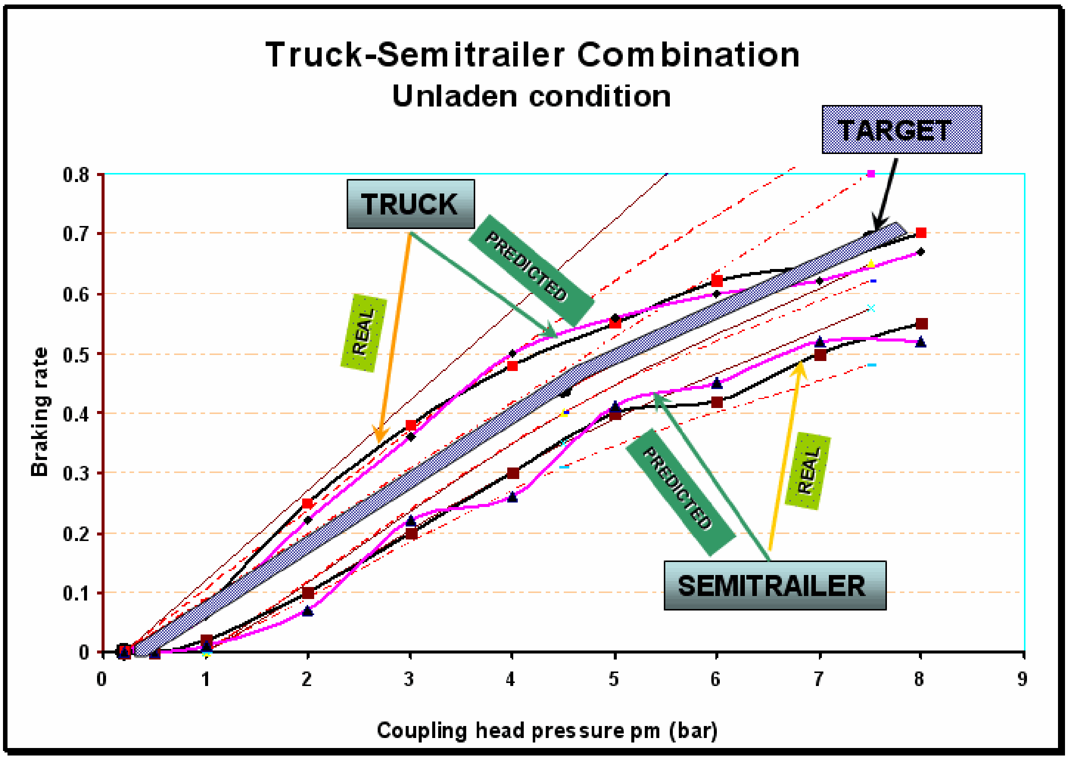

Fig. 6. The tractor/semi-trailer braking system function modelling

CONCLUSIONS

Intelligent Control of Vehicle Combination Braking Compatibility (ICVCBC) is an "add-on" system, and its application does not impose any restriction concerning existing ESP devices already used in vehicles. It has a task to enable solution to the problem of vehicle combination braking compatibility in a more accurate way then it was the case now a day, by means of over-taking responsibility for intelligent control of the tractor/semi-trailer (trailer) braking systems function.

Here proposed intelligent tractor/semi-trailer braking systems operation is supposed to enable not only to monitor operation of every component of a braking system but also to undertake all necessary actions to provide that braking system at any time and under any usage conditions offer the maximum of its actual capabilities. That is why, the target functions of the braking rate lines versus control line pressures and load condition of the vehicle combination have been introduced. Adaptive EBS control function would be able to model real braking systems performance versus different operation conditions. It is extremely important that braking systems function for both tractor and semi-trailer (trailer) is known i.e. modelled in order to be able to select the proper control inputs and provide identical tractor/trailer partial decelerations according to selected braking strategy.

The main benefit of the proposed intelligent control strategy is that future decisions related to the braking systems control are based on the neural models of tractor/semi-trailer braking systems operation. That is why the control inputs (the index pressures) for the front and rear axles of the towing vehicle as well as coupling head pressure for the trailer vehicle could be adjusted for different operating condition offering the maximum capabilities of the braking systems function in the three different control range: (i) normal braking, (ii) wear control, and (iii) panic braking.

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