VALIDATION PROCESS FOR ESP BASED ELECTRIC STEERING SYSTEM

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Abstract

Stability problems of vehicles, especially commercial vehicles, get more and more attention with the increasing traffic load of the roads. The development of infrastructure can not follow the demands for the increasing traffic and it result in increasing number of accidents. The society can not accept this situation and it raises higher and higher demand on the active safety of the vehicles. This demand resulted that the brake system based drive stability systems are available today and in some cases are obligatory.

If the driver demanded vehicle motion (which is calculated on the basis of a reference vehicle model) differs from the measured vehicle motion, the system applies a moment using the brakes to force the vehicle to move on the desired path. However the brake is activated without the direct command from the driver, the system can not be considered as an autonomous driver assistant system, because it just supports the driver to reach his demand. The driver is a part of the control loop completely.

The target of the paper is to extend the drive stability system with active steering intervention. The new generation steering systems with the help of a superimposing gear can manipulate the steering angle, and so they can manipulate the acting forces of the tire contact point. So the new generation of the ESP requires the appropriate steering system. As a part of the current development the adequacy of the model is checked by a validation process with a continuous feedback.

Keywords: *vehicle, steer, brake, ESP, model*

1. Introduction

Producing vehicles is one of the leading industries on the entire world, thanks for the constantly altering demands which are, because of the flare of the vehicular systems [4]. And on the other hand this area is perfect for the use of the newest scientific results. Regarding the vehicles it is self explicatory that the developing of the automobiles is the leader in the installation of the new technologies, because that makes a more subjective market. The biggest part of the electronic systems are available in the automobiles (as an option or included in the basic trim level). But the development of the modern, electronically controlled vehicle systems in case of the commercial vehicles was a lot slower than the development at the automobiles. All of this is because of the particularities of the commercial vehicle market. In case of a commercial vehicle, the primary point of view of the customer is the business return and profit, which infers the conservative composition of the market. The vehicle has to generate profit, which can be achieved with a low purchase price, low upkeeps, long lifetime and good utilization. These aspects are contradictory to the use of the more expensive newest technical solutions as long as its benefits become more economically realizable and reachable. With the growing of the vehicular traffic the social demand for security increases as well. At the speedily rise of the traffic, the vehicular infrastructure is unable to match the contradictory conditions of the safe transport and the growing efficiency, namely it is unable to lead away safely the dense traffic. In the growing traffic which accompanies the development of the economy the risk of an accident is higher, which worsens significantly the economical efficiency. The contradiction which lies in the growing traffic density is impossible to resolve, but with some certain methods the operation of the vehicular systems is optimizable. With the use of intelligent vehicles and the establishment of an intelligent infrastructure – partly with the support of the human participants of the system –the efficiency of the vehicle control can be increased, which can make possible the crashfree controlling of a bigger traffic density [6].

2. Dynamic properties of heavy duty vehicles

The motion dynamics of commercial vehicles – like their application goal area – is largely different from the automobile's, but it depends highly on the class of the vehicle. Regarding the ISO 3833 standard, a truck can be solo, equipped with a trailer or a semitrailed vehicle unit, or a so called polynomial unit (for example a road train which is composed of an engine or a trailed unit and a bobtail, and the carriages. Generally we can say that the essential differences from the automobiles, regarding the vehicle dynamics can be deduced from the composition (class) of the vehicle, its weight, the position of its centre of mass (usually it is located much higher), and from the different attributes of the tyres. Of course because of the different sizes, composition and weights, we can see other solutions, adjustments in a commercial vehicle in the drive system (engine, power train) and in the security critical subsystems (brake – steering system) as well which are different from the ones in an automobile, depending on how much do its size and capacity exceed the ones of a regular vehicle. Regarding the vehicle dynamics behaviour, the dangerous vehicle movements can be classified into 3 typical classes in case of the commercial vehicles. Accordingly the first group is the jack – knifing which is peculiar at vehicle units equipped with a trailer, when the longitudinal axis of the engine and the trailer include an inregulatedly big angle, which increases the transversal slip at the driven rear axle of the towing vehicle. Above a certain value of this jack-knifing angle, with the steering of the towing vehicle it is impossible to control the vehicle movements, so the motion of the vehicle becomes unstable. In addition before reaching the critical value of the jack-knifing angle the driver can even worsen the situation with an inadequate steering correction. An other characteristic dangerous motion form of the vehicle units equipped with a trailer is the transversal oscillation of the trailer, which can derive from the disturbing effects which take effect on the vehicle (for example side-wind, sudden steering, etc.). It can mean an unusual danger that in this case the vehicle can easily become self-impulsive, so it can happen that the motion of the vehicle becomes unstable after the end of the disturbing effect, perhaps in a completely unexpected form or direction. For the third dangerous motion form we have to mention the angle movement along the longitudinal axis, so the overturn, which can cause extremely high damages in accidents. Generally the supervention of the overturn is explained with the wrongly chosen speed. The motion of the vehicle can be considered stable until the supervention. The overturn occurs when the angular force (about the mass centre) of the transversal force can not be compensated by the vertical force pair which starts on the wheels. At the cornering movement the transversal force matches the centripetal force depending on the speed. There is an other difficulty with the overturn, that from the towing vehicle it is hard to sense the tilting of the trailer before a certain point when the motion is impossible to stabilize at [5].

3. Motion dynamics assistants

In accord with the goals of the European Union the further development and introduction of the motion dynamics assistant systems is an elemental aim in favour of reducing the number of the serious, highly harmful accidents caused by commercial vehicles.

Nowadays there are some available motion dynamics systems (optionally) in the vehicles found on the market. They are constantly developed, because on the one hand the efficiency of their operation can be corrigible, and enrichable with new functions. However the new functions involve higher and higher complexity which can increase the producing and maintain / repairing costs on the highly price-sensitive commercial vehicle market.

The main goal of the project is increasing the efficiency of the motion dynamics controlling in heavy commercial vehicles combining the main safety-critical vehicle-subsystems, the brake- and steering systems, harmonizing their operation. With the using of the synergy effects we create the basics of a central control unit which includes the controlling of the entire vehicle motion and a simplified vehicle-architecture.

4. On-road situations

At a neutral turning behaviour the vehicle is able to follow entirely the trajectory wanted by the vehicle driver at a given speed. The size of the transmissible side-forces depend among others highly on the wheel load – in addition we have to count also with a cross-loading – on the characteristics of the tyre (tyre pressure, profile depth, the rigidity of its sidewall), and of course the adhesion coefficient of the road surface determines whether the force efforted by the driver can entirely evolve.

In case of a limited transversal adhesion coefficient the required side-force does not evolve on the wheels. If this evolves on the front wheels then the vehicle becomes understeered. The understeered vehicle heads to the external margin of the curve, it goes off from the wanted path. At this time the direction of the base point speed highly deviates from the tangential direction of the path, so their side-crawling angle is big.

The diminution of the transmissible sideforce of course can be caused by the tyre as well, and not necessarily is deduced from the adhesion coefficient of the road. As long as the side-crawling angle of the rear wheels exceeds the one of the front wheels in the course of the manoeuvre – so the rear wheels are unable to transmit the desired side-force – then the vehicle becomes oversteered. The sideforce which is transmitted on the base point of the wheel is highly determined by the longitudinal force which occurs there.

In this case our main goal is creating a driver assistant system installed in heavy commercial vehicles, which can increase the safety of the transport, and which is able to prevent the initiation of an incidental unstable motion state in an autonomous way, with the driver staying in the controlling loop, so the driver defines the trajectory of the vehicle and is responsible for it. In case of need the controlling system performs the intervention in a way which is unsensible for the driver in order to the fact that the vehicle can head along a path defined by the driver with a speed wanted by him if that is possible. Of course the driver has to be informed somehow about the performed intervention.

5. Brake systems

Regarding the safe transport, the most important is the brake system. The EBS electronical brake system was created in order to prevent the problems of the air-brakes, and can include a lot of functions (ABS, ASR, etc) and it can control the speed of each wheel independently in the entire slip-range. The primary aim of the further developments is realizing an entirely electronical brake system (brake-by-wire), in which the air stays the working agent. The next step is the exchanging of the pneumatics with creating an electromechanical system, where the wheelbrake-devices are operated by electromotors.

6. Steering systems

There are less differences in the steering systems of commercial vehicles and automobiles than in the brake systems. A temporary solution is at the cars of this era is a hydraulic steering help powered by one electromotor (the EHPAS – Electro-Hydraulic Power Assisted Steering) which tries to combine the positive characteristics of the EPAS and HPAS until the domination of the EPAS.

In these systems not the explosion engine but a separate electromotor powers the servo hydraulic-pump. At the electronical servo-helped steering system (EPS or EPAS – Electronic Power-Assisted Steering) the assistant torque is created by an electronic motor. The operation of this motor can be electronically controlled, which leads to advantages in the field of driving-convenience, safety and economy. The rate of the assistant torque can be made dependent not only on the driver's demand signed at the steering wheel but on other parameters as well, such as the speed of the vehicle or the steering angle itself. However this system is not an entirely electronical steering system (SbW – Steer-by-Wire), because the mechanical connection remains between the steering wheel and the steered wheels, and with the help of it, we can create torque without the direct torque demand of the driver, which we can total with the driver's direct torque demand. This way a lot of new functions can be realized: assistance depended on the speed, side-wind compensation, etc. According to the forecasts the trend of the development will be different on the market of the commercial vehicles, because the torque provided by electromotors is unsatisfactory in case of the commercial vehicles with bigger axis-load. That is why in the commercial vehicle segment

The „regular" hydraulics pump powered by an explosion engine remains, only the rate of the assistance will decrease and beside the hydraulic assistance an electric motor will help the steering as well. This electric assistant torque is however controlled depending on the motion-convenience- and economic demands. This motor starts to work, when aside of the hydraulic assistance a bigger assistant demand arises (for example at slow motion, parking, etc) and turns off when its assistance is no longer needed or the hydraulic servo is enough for the required assistance. The system possesses with the advantages of the entirely electronic assistance: Its operation and power demands are easily controlled by the current demands, the assistant functions are realizable with the help of the system. If we add an angle with a constantly controlled value to the steering angle demanded by the driver, then we change the drive of the steering machine. The value of the added angle can depend on more factors, for example: speed of vehicle, transversal acceleration, etc. The additive angle motion can be created in the easiest way by a well-controllable electromotor, which connects to the steering column through some drive. So the system can interfere in the steering without the torque efforted by the driver on the steering wheel. In this case the continuity of the steering system comes to an end, which we close through a self-closing drive powered by a motor. The active steering system gives no torque that is why it is necessary to complete with a servo system, which acts upon the force, which the wheels need to be steered with. The next level of the evolution is a fully electronic steering system without the mechanical connection (SbW – Steer-by-Wire). Since there is no connection between the steering wheel and the steered wheels, an angle-signal transmitter senses the turning of the steering wheel, on the grounds of which the control unit regulates the operation of the actuator, in a way that the steering angle wanted by the driver can come true.

7. Electronic Stability Program (ESP)

The stabilizer electronics is not else than the kind of wheelslip-controlling for optimizing the transversal dynamics. The task of the system is helping the driver in keeping the vehicle on track. The automatic stabilizer system based on the ABS / EBS hydraulics / pneumatics unity recognises and handles the critical motion-states. It stabilizes the motion of the vehicle with the differentiated braking of the wheels and controlling of the engine torque, without the need for the driver of stepping on the brake or accelerator pedal. The torque – controlling keeps the torque about the vertical axis which goes through the mass centre of the vehicle between certain values. Before the vehicle could spin, skid or drift the electronic control unit detects the dangerous motion state and interferes based on the signals of the sensors. In the course of its operation the system determines the optimal response given by the vehicle by replying to the demand of the driver based on the angle of the steering wheel and the speed of the vehicle. The sensors measure the cross acceleration of the car body and the yaw rate (and the pressure of the brake system) beyond the speed of wheels. The difference between the effective motion state calculated based on these signals and the desired motion state gives the direction, the method and the measure of the intervention. By the intervention the electronic control unit operates the appropriate valves of the hydraulics / pneumatics unity and the brake fluid pump, and the air-providing system as well, and it gives orders to the engine controlling electronics for regulating the motoring torque. The ESP modifies the base point of the wheel longitudinal and correlating transversal forces so that the torque will be optimal sized. In favour of reaching the neutral steering characteristics, the vehicle stability assistant brakes the inner rear wheel of the understeered vehicle and the outer front wheel of the oversteered vehicle.

That is how it modifies the direction and the torque of the resultant force on the base point of the wheel to the vertical axis. The size of the created torque is proportional to the triangle composed of the difference of the modified and the original wheelforce and the mass centre on the force-diagram. When a vehicle is equipped with a trailer of course the right intervention has to be performed on the trailer. With the braking of the axises of the trailer the main goal is the prevention of the jack-knifing.

We can tell about the vehicle stability assistant vehicle-dynamics controlling system, that with the modifying of the base point of the wheel forces it controls efficiently the motion of the vehicle also at the stability borders, it can make possible the steering of the vehicle even in critical situations independently from the cause of the instability.

7.1. Brake based vehicle stability

One of the most effective tools for stabilizing the motion of the vehicle is the brake system, because:

- It has a high power absorber capacity (4 brake discs can dissipate more than 10000 PS-s),
- It is proper for modifying the transversal (lateral) wheel forces (not only for slowing down the vehicle),
- It is able to control in the entire slip range (in longitudinal, and lateral directions as well),
- The brake intervention for each wheel is realizable with the current brake systems (EBS) – even independently from the driver – it does not need a new actuator.
- The necessary additional sensors for the EBS for realization of the motion dynamics controller: Yaw rate, cross acceleration, and steering wheel angle.

7.2. Steering based vehicle stability

The steering system is the number one tool of the cross-directed motion control, because you can modify the sideforce which acts directly upon the wheels.

- It modifies directly the side force,
- It realizes the desired base point of the wheel force and the torque about the vertical axis without a radical speed decreasing,
- It is impossible to control in longitudinal and transversal slip range with the help of it.

Until a certain steering wheel angle you can tell that the transversal force's torque about the vertical axis which goes through the mass centre of the vehicle is bigger thanks to the bigger arm of the force (since the wheelbase is generally bigger than the wheel track)

The motion dynamics control system completed with the steering wheel- intervention can work similarly to the regular brake based ESP, based on the differences between the desired and the current motion state of the vehicle, because its main goal is to minimize this difference.

As a possible solution after the plausibility examination of the inputs the logic processes the incoming sensor data, which give information about the current motion state of the vehicle, so it reproduces the „measured" motion vector. The reference model which is a part of the algorithm performs the calculation of the motion vector values desired by the vehicle driver. So it is possible to calculate the differences between the „desired" and the „measured" values. The rate of the brake- , steering- drive train- interventions are based on the size of the differences from the desired and measured motion vectors with appropriate controlling-associates (for example PID)

The definition of the motion-vector depends on the complexity of the reference model, and on what kind of characteristics are available processing the signals of the sensors placed on the vehicle. The use of the jaw-rate is obvious as an element of the motion-vector, because that is the amount measured directly on the vehicle. However it would be desirable using the floating-angle of the vehicle for comparing the desired and measured motion states, because it is easy to characterize the stability of the vehicle with its help. The calculating of the floating-angle (or the side-crawling angles of the axises) can be performed with an additional sensor, or you have to forecast it from the other vehicle characteristics. The disorder compensatory part of the algorithm can be completed with a predictive function, which has a great significance in the μ-split braking. In this case we try to terminate the effects of the torque derived from the different brake-forces at the two sides of the vehicle by a steering wheel intervention. So before the initiation of the jaw rate (spinning) we can draw conclusions from the sizes of the brake-forces to the size of the torque which caused the effects, which can result in a more accurate and fast execution of the required steering wheel intervention.

7.3. Steering based system advantages of brake based

Based on the requirements and proposals the motion dynamics control system combined with the steering wheel intervention can be more effective than the regular brake-based stabilizer system.

- It is a more sensitive system. The steering wheel intervention can be performed in the dead-range of the brake intervention, because it is a less powerful intervention, it barely effects the steering convenience,
- It is a more effective system. It escalates the effectiveness of the regular brake-based system when it is completed with a new actuator, which is easier to operate (see previous point), and on the other hand it is able to modify the direct transversal force, and in addition it can generate on a bigger moment torque in the mass centre of the vehicle. (wheel base → wheel track). It clearly has an advantage on the shared adhesion coefficiented surface of the system, where-while the regular brake based system is inactive – at start and at braking as well it acquits the driver of the counter steering. Combined with the functions of the ABS the braking distance can be shorter with the use of the steering wheel intervention,
- It is a more convenient system. While the more sensitive steering wheel intervention provides sufficient help in realizing the desired motion path (in the dead-range of the brake-based system), the speed of the vehicle does not decrease significantly.

8. Vehicle models

When it comes to regulating ESP there are three model vehicles. The inputs are the steering angle (steering requirements), the engine torque and the braking force, while the Yaw-rate itself serves as the output (see Fig. 1.). We define the lateral steering ability of the wheels of the one-track linear state space-model with the help of the parameters measured on actual vehicles that serve as inputs for the ESP regulation. Besides checking the usual signals we also monitor the brake-pressure since the transmissible longitudinal force changes at braking. Grip coefficients are defined against the neutral position. The resulting ideal course is marked by the ideal angle speed.

Based on this and depending on the invariably known spin coefficient difference, the regulator can define the steering angle and brake-force required at the moment of the ESP intervention. However, there are variables that the regulator cannot handle, such as side-wind.

The ideal route, which can be modelled as a route free from exterior forces, emerges as one based on speed and steering angle. Nevertheless, in case of a real route the model has to be compensated [1].

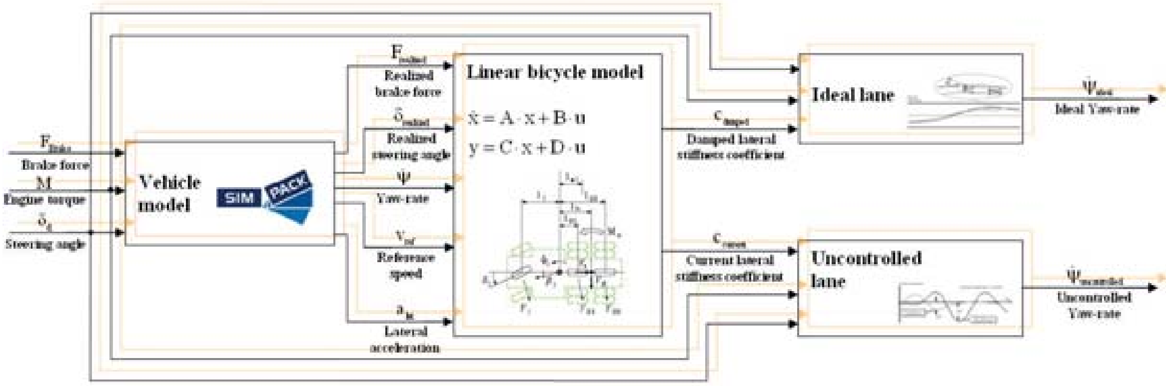

Fig. 1. Connection of lane subsystems

A soon as the need for steering and compensation vanishes the system can return to its original status. Due to the unexpected effects such integrating regulation is needed that defines not the degree of intervention but its direction and intensity and as such it performs a consecutive compensation.

The control-circle operating on the grounds of steering intervention has to be connected to the one functioning based on the brakes to make sure that braking would compensate for the stability of the vehicle, should steering intervention prove insufficient (see Fig. 2.). An additional reason for braking intervention is that you have to decrease the speed of the unstable vehicle and this cannot be performed by the steering gear but what is more, the steering gear can, in certain cases, indirectly increase the speed of the vehicle [1].

The steering intervention is limited by its marginal values after which you cannot turn the wheel any more. The time needed for the intervention and its effectiveness are two other limiting factors. It should be clear that after surpassing a certain steering angle tread wear increases so significantly and stability decreases so drastically that it s more advised to try to adjust by braking. Furthermore, in the course of braking the lateral steering force of the tyres may diminish or be gone completely which means that using the brakes and the steering wheel simultaneously as an ESP intervention will not always deliver the necessary results [3].

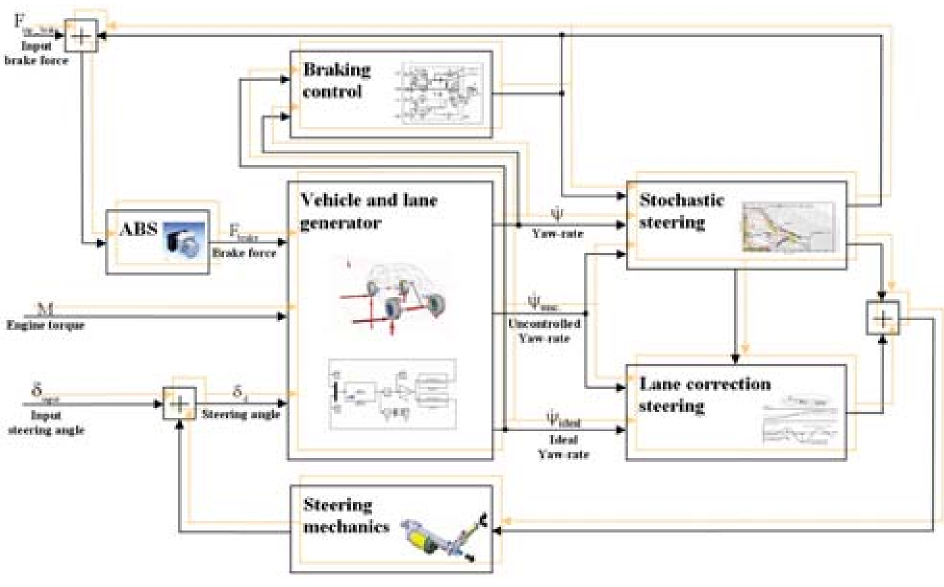

Fig. 2. Connection of braking control and steering modules

In order to improve the situation we have to set up a controlling system where, at the moment of the intervention, we monitor not only the current steering position, the direction and the desired extent of the intervention but also such a constant value as the maximum counter-steering angle. Furthermore, we also have to define the extent of braking depending on these values. Obviously, with regard to the effectiveness of the intervention, braking is prioritised so when surpassing the value of the critical stability limit the system would intervene by braking but should the value above drop to a more acceptable level the system would respond by taking away the transmitted brake pressure and let the additional counter-steering get involved.

9. Steps of the developing process

As the first step of the developing process we have to define the running borders of the intervening subsystems [2]:

- Brake system: maximum brake-pressure, the speed of pressure increasing and decreasing, cycle time of slip-controlling, measurement borders, and accuracy of the additional ESP sensors, etc.,
- Steering system: maximum steering wheel angle, base drive, the maximum torque, performance, controlling cycle-time, of the electric motor which executes the correction, accuracy and measurement borders of the steering wheel-angle transmitter, etc.

In view of the inputs and outputs the next step can be the definition of the interfaces. The functionality and communication can be tested in the early period of the development, when we choose the appropriate software for programming the controller, which can allow us to run real-time the logic in some hardware unit, which has the necessary communication ports.

References

[1] Wallentowitz, H., *Vehicle Dynamics with Adaptive or Semi-Active Suspension Systems, Demands on Hardware and Software*, Electronic Steering and Suspension Systems, pp. 437-442, 1999.

[2] Kovács, R., at all, *Aktív kormányzással támogatott ESP*, Budapest University of Technology and Economics, Budapest 2008.

[3] Pacejka, Hans, B., *Tyre and Vehicle Dynamics, Elsevier Butterworth-Heinemann*, pp. 16-62, 2002.

[4] Palkovics, L,. *Intelligens Járműrendszerek*, www.mindentudas.hu, Budapest 2005.

[5] Brunnschweiler, D., *Requirements Engineering and Test Engineering are the backbone of safety critical system development*, Thyssen Krupp Presta, Budapest 2008.

[6] Palkovics, L., Szalay, Zs., *Electronic Stability Program*, Gépjármű Elektronika, Budapest University of Technology and Economics, Budapest 2006.