DIAGRAMS, FUNCTIONAL AND CONSTRUCTIVE SOLUTIONS OF THE STABILITY CONTROL SYSTEMS FOR AUTOMOTIVE APPLICATION

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Abstract: *The modern car must correspond to certain requirements regarding the driver safety and more than that it must convince the potential buyer that it will offer him the safety he is so much in need of. For that reason the number and the diversity of the safety systems have increased so fast. Despite all this for the time being it can not be stated that a particular vehicle is totally safe and it can come through any difficult situation. Because of that the research in the field is carried on and the number of those who propose solutions mend to improve the vehicle behavior is getting bigger.*

Key words: active safety, vehicle, control

1. Introduction

There are three issues in the research of the vehicle stability control systems. These issues include the observer design for estimating the vehicle states difficult to measure directly, the vehicle stability controller design for the lateral motion and the actuator control for the acquisition of the yaw moment through the distribution of the braking forces. In this study, it is investigated the controller design issue and left other for future study. Shibahara [l] proposed a method called "I-method" for the vehicle stability controller design and discussed how the yaw moment generated by the lateral force of the front and rear wheels changes in response to the vehicle sideslip angle. Matsumoto [2] reported the yaw rate model following control with the yaw rate feedback but fail to advance considerable performance improvement on the low friction road. Alberti [3] proposed a control strategy for controlling the sideslip rate in addition to the yaw rate. Inagaki [4] analyzed the stability of vehicle motion by the phase-plane of the sideslip angle and proposed a brake forces control law depending on the yaw moment. Shibahara pointed out the instability of vehicle is caused by the decrease of the restoring yaw moment as the vehicle sideslip angle increases. In addition to the previous analytic approach, many researchers have proposed the vehicle stability controllers based on the nonlinear control design methodologies. Recent studies based on the adaptive control, H-∞ control and |i-synthesis have been proposed [6]. Yoshimi[7] proposed the sliding mode control and Tohru [8] designed the sliding mode controller with the sideslip angle and yaw rate feedback. Commercial systems including the VDC (Vehicle dynamic control system) of BOSCH, the VSC (Vehicle stability control system) of Toyota, and the ESP (Electronic stability program) of ITT et al. have been developed mainly based on the experimental knowledge.

In [13] the direct yaw moment controller (DYC) is used, in which the yaw moment on the vehicle is supplied directly. DYC is the approach of the controller design for maintaining the handling stability by means of controlling the longitudinal and lateral vehicle motion. The traction force, the braking force and the steering angle can generate the desired yaw moment input in general. In [13] it is assumed the yaw moment input can be realized through the distribution of the braking force at individual wheels because this approach is simple and effective.

As the vehicle stability control system guarantees the vehicle stability by means of controlling the vehicle motion corresponding to the driver's will, the controller should use the reference model that could express the driver's will. Most of previous studies have used the yaw rate reference model with the yaw rate feedback that could be measured easily. Though the vehicle with the yaw rate feedback could follow the reference yaw rate on the low friction road such as ice, it could not trace the slip angle and need significant driver's steering efforts. The latest research proposed the slip angle feedback; these have the limitation for the real application because of the requirement of the differentiation of the measurement. [7]

In [11] the authors propose a vehicle stability controller based on the multiple siding mode control approach in order to overcome the uncertainty and the nonlinear behavior of the real vehicle. The proposed controller feeds back both the sideslip angle and makes the sideslip angle track the desired one so that it guarantee the vehicle stability on various driving conditions. It is shown the feasibility of the proposed controller through computer simulations based on a nonlinear fifteen degree-of-freedom vehicle model with the UA tire model, which has been verified through the experimental vehicle test.

In [10] in contrast to a conventional ESP, not only the yaw motion and the vehicle side slip angle but also the lateral motion with respect to the driving lane is stabilized.

A nonlinear control concept based on online design of a Riccati-controller is used to obtain a stabilizing steering angle. In order to make use of the maximally available side force and to reduce the effects of changes in road friction, the side slip angle at the wheels is limited based on a nonlinear side force model.

Based on the nominal controller a range of reasonable steering angles is defined to assess, whether the driver steering is adequate or an intervention by the PVD System is necessary to stabilize the vehicle.

In [9] it is developed vehicle side slip angle and tire side slip angle estimation logic. Also, it is necessary to estimate road surface friction coefficients in order to respond to various road surfaces. Furthermore, the vehicle’s yaw moment and side slip angle are corrected with the optimal 4-wheel slip control logic. All this is created using data like steering angle, longitudinal acceleration, lateral acceleration, yaw rate and wheel velocity.

The method for estimating vehicle side slip angle is a logic that can estimate forces on each tire by combining the conventional two tire vehicle model and nonlinear tire model.

The μ estimation logic is the most important issue in this research. The aim is to estimate the limit conditions in the worst possible scenario and in order to achieve that four separate calculations are made.

In [12] the aim is to develop a generic controller design methodology that can be used with existing chassis subsystems controllers.

The controller monitors the driver’s demands and the state of the vehicle motion to produce safe and comfortable motion by actuating the drive, steering, suspension and brake subsystems. The supervisor is aware of vehicle parameter changes and can adapt the controller accordingly.

The sliding mode controller can provide excellent setpoint tracking performance in terms of response speed, overshoot and settling time. In terms of robustness, there are limits on what can be achieved. These limits are influenced by the friction force available at the wheel and the desired setpoint to be reached by the controller. It is pertinent therefore to identify an operating envelope for the controller in terms of the friction force available at each wheel and the maximum longitudinal and lateral forces achievable.

2. Electronic Stability Program (ESP) for passenger cars

2.1. Function

The Electronic Stability Program, ESP, is a closed-loop control system integrated in the vehicle's braking system and drivetrain which prevents the vehicle from breaking away to the side. While ABS (Antilock Braking System) prevents the wheels from locking when braked and TCS (Traction Control System) prevents the driven wheels from spinning, ESP prevents the vehicle from "pushing out" of the turn or spinning out of the turn when it is steered.

Further to the benefits of ABS and TCS, ESP improves active driving safety in the following points:

-Provides the driver with active support, even in critical lateral dynamic situations.

-Enhances directional and vehicle stability even at the vehicle's physical driving limits in all operating statuses, such as full braking, partial braking, coasting, accelerating, engine drag, and load changes.
-Enhances directional stability even in extreme steering maneuvers (fear and panic reactions), resulting in a drastic reduction in the risk of skidding.
- Improved handling also at the vehicle's physical driving limits. For the driver, handling becomes predictable as a function of the driver's driving experience. The vehicle remains fully under control even in critical traffic situations.
-Depending on the situation, enhanced utilization of the friction potential between the tires and the road when ABS and TCS intervene, and therefore improved traction and braking distances in addition to improved steerability and stability.

2.2. ESP control systems

The control of the handling characteristics at the vehicle's physical driving limits must influence the vehicle's three degrees of freedom in the plane of the road (linear and lateral velocities, and yaw velocity about the vertical axis) so that vehicle handling is adapted to the driver command and the prevailing road-surface conditions. In this respect, as shown in the block diagram, it must first be defined how the vehicle is to behave at its physical driving limits in accordance with driver command (nominal behavior), and how it actually behaves (actual behavior. In order to minimize the difference between nominal and actual behavior (deviation), the tire forces must in some way be controlled by actuators.

The overall system (figure "Overall control system of ESP" below), shows the vehicle as a controlled system, with sensors (1...5) for defining the controller input variables, and actuators (6 and 7) for influencing the motive and braking forces. Also shown are the hierarchically structured controller, comprising the higher-level vehicle dynamics controller, and the lower-level slip controllers. The higher-level controllers determine the nominal values to the lower-level controllers in the form of nominal slip. The "observer" determines the controlled state variable (float angle β).

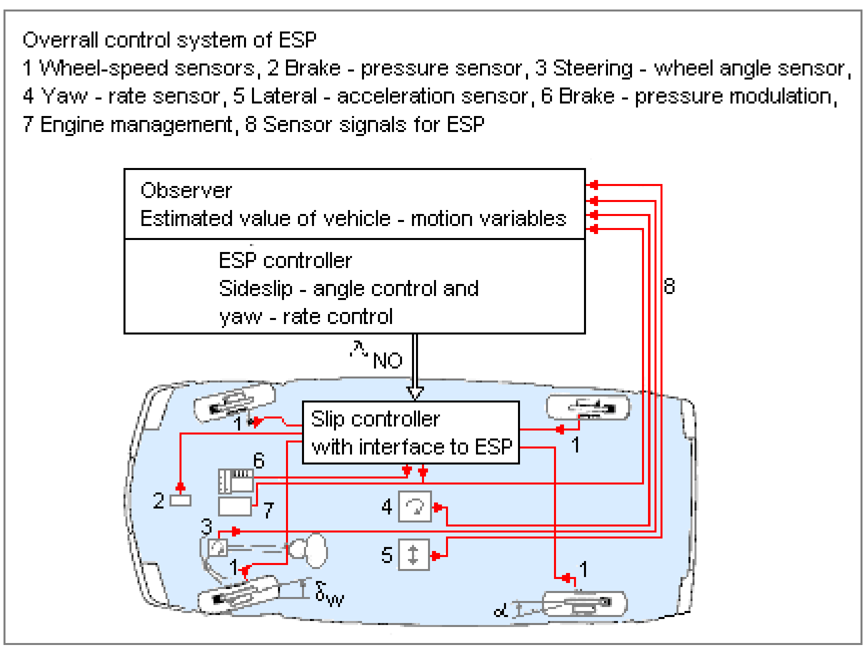

Fig. 1. *Overall control system of ESP*

In order to determine the nominal behavior, the signals defining driver command are evaluated. These comprise the signals from the steering-wheel angle sensor (3, driver's steering input), the brake-pressure sensor (2, desired deceleration input), and the engine management (7, desired drive torque). Apart from the vehicle speed, the calculation of the nominal behavior also takes the coefficients of friction between the tires and the road into account. These are calculated from the signals sent by the wheel-speed sensors (1), the lateral-acceleration sensor (5), the yaw-rate sensor (4), and the brake-pressure sensor (2). Depending on the control deviation, the yaw moment, which is necessary to make the actual-state variables approach the desired-state variables, is then calculated.

In order to generate the required yaw moment, it is necessary for the changos in desired slip al the wheels to be determined by the vehicle dynamics controller. These ore then set by means of the lower brake-slip and traction controllers together with the "brake-hydraulics" actuator (6), and the "engine-management actuator" (7).

The system relies on tried and proven ABS and TCS components. The TCS hydraulic modulator (6), which is described elsewhere, permits high levels of dynamic braking of all wheels throughout the complete temperature range encountered.

The necessary engine torque can be set by means of the engine management (7) and the CAN interface, so that the traction-slip values at the wheels can be adjusted accordingly.

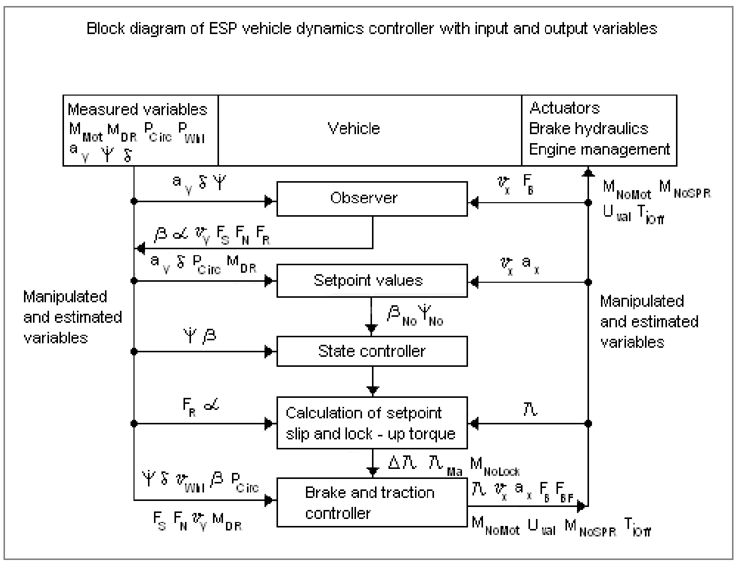

Fig. 2. *Block diagram of ESP vehicle dynamics controller*

The items which appear in the diagram above are listed below:

a_x Estimated vehicle longitudinal acceleration

a_y Measured vehicle lateral acceleration

D_λ Tolerance band of drive-slip difference between driven wheels

F_B Tire braking force

F_{BF} Steady-state (filtered) braking force on the tire

F_N Vertical tire force (normal force)

F_R Resultant tire force

F_S Lateral tire force

M_{DR} Driver – input engine toque

M_{Mot} Actual engine torque

M_{NoMot}	Nominal engine torque
M_{NoLock}	Nominal brake-locking torque at the driven wheels
M_{NoSPR}	Nominal engine-torque reduction by spark retard
p_{Circ}	Brake-circuit pressure induced by the driver
p_{Whl}	Pressure in wheel-brake cylinder
$T_{.jOFF}$	Injection blank-out period
U_{val}	Valve-triggering mode
υ_{Vhl}	Measured wheel speed
υ_x	Vehicle linear velocity
υ_y	Vehicle lateral velocity
α	Tire slip angle
β	Vehicle float angle
δ	Steering-wheel angle
λ	Tire slip
λ_{Ma}	Average nominal traction slip of the driven wheels
$\dot{\Psi}$	Yaw velocity

3. Vehicle Stability Assist

The Vehicle Stability Assist (VSA) system adds side slip control to ABS and TCS systems. This system controls sudden changes in vehicle behavior, giving the driver the time to keep control of the situation. When driving in the rain or on snow, the system stabilizes the vehicle, reducing counter-productive driver tension.

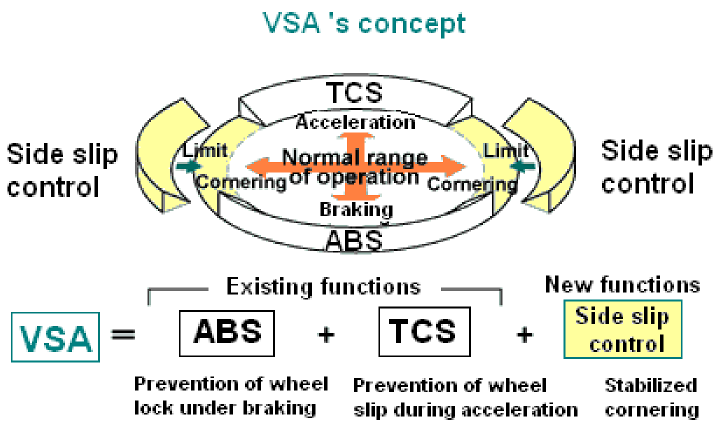

Fig. 3. VSA's functioning principle

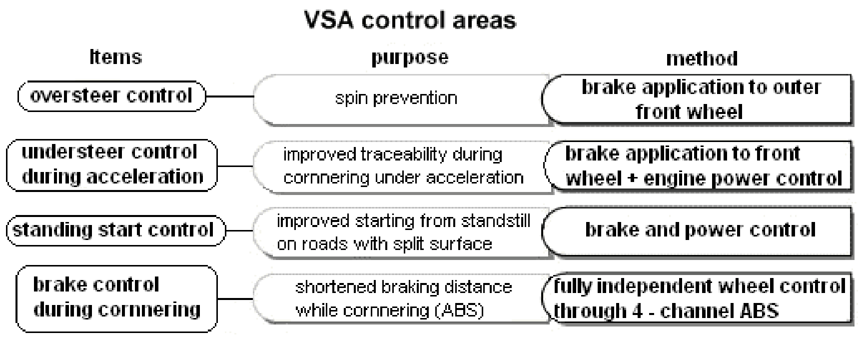

Fig. 4. *VSA's control areas*

The system controls the oversteer tendency of the vehicle by braking the outer front wheel thus generating an outward moment. The cornering force at the front is thus reduced, decreasing the spin generating moment and stabilizing vehicle behavior.

When the car's cornering line widens under excessive throttle application, the system intervenes by reducing engine torque and, if necessary, by braking the inside front wheel. This creates an inward moment helping the car trace the line originally intended by the driver.

The yaw rate intended by the driver (target yaw rate) is calculated according to lateral acceleration, steering angle and vehicle speed. If the actual yaw rate exceeds or is below the target, the VSA system intervenes.

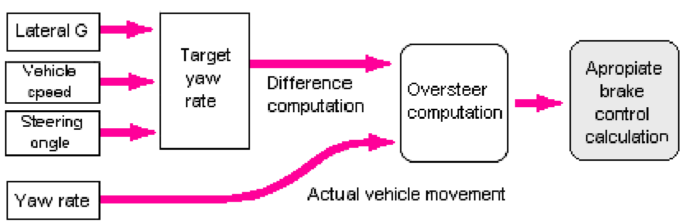

Fig. 5. *Oversteer control strategy*

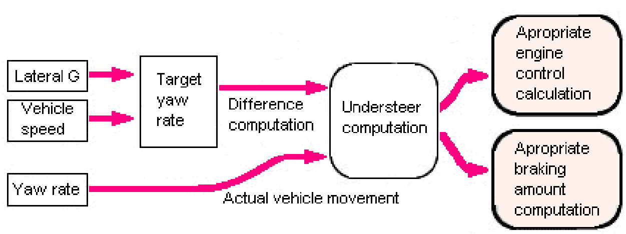

Fig. 6. *Understeer control strategy*

3.1 . Standing Start Slip Control

When accelerating on a split surface with different grip coefficients, engine torque is usually transmitted to the wheel with the lowest grip level, resulting in traction loss. By braking the wheel with the lowest grip, greater torque is provided to the wheel on the other side, ensuring quick, powerful acceleration.

3.2. Braking control under cornering

When high cornering forces are detected, ABS automatically switches to the 4-channel mode (3-channel mode when in a straight line or when cornering at lower speeds). Taking advantage of the weight transfer during cornering, the system applies a higher brake pressure on the outer rear wheel, improving braking performance.

3.3. System Configuration and Principal of Operation

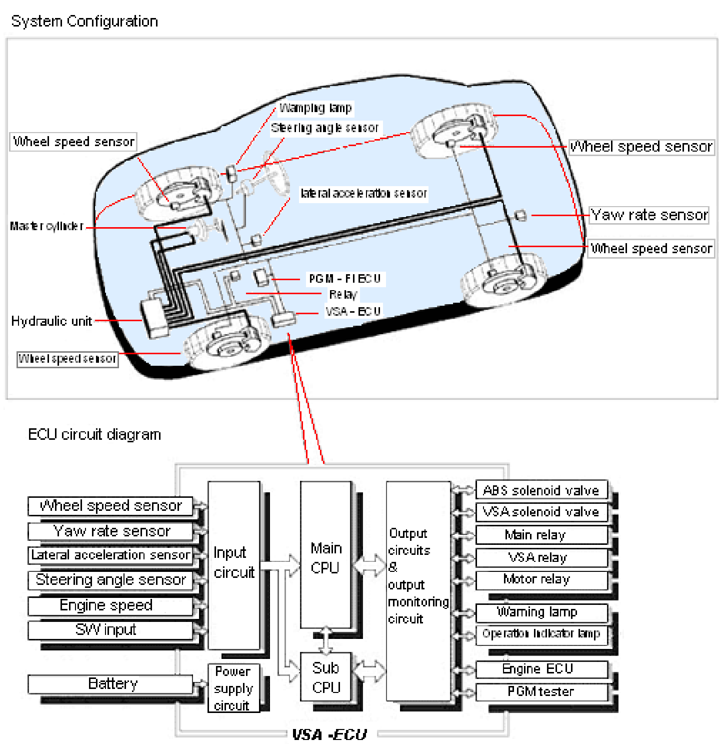

Fig. 7. *System configuration*

4. Conclusion

The impact of the control systems to the fluency of the traffic under safety is in continuous growth and their evolution must be linked to the real necessities of the driver so that the control system and the human being act like a single system.

In this respect the control systems the driver comes in contact with must be discreet and they must guess the driver's intention and act immediately eliminating thus the human imprecision and uncertainty.

All of these modern systems represent a plus of safety for the driver providing him a real support in different difficult driving situations.

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