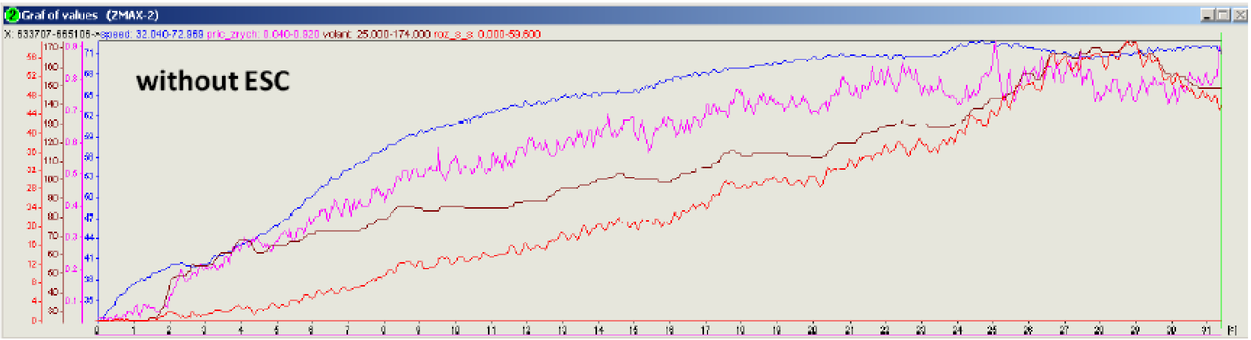
Research Report
Influence of Vehicle Assistant System
on Track keeping

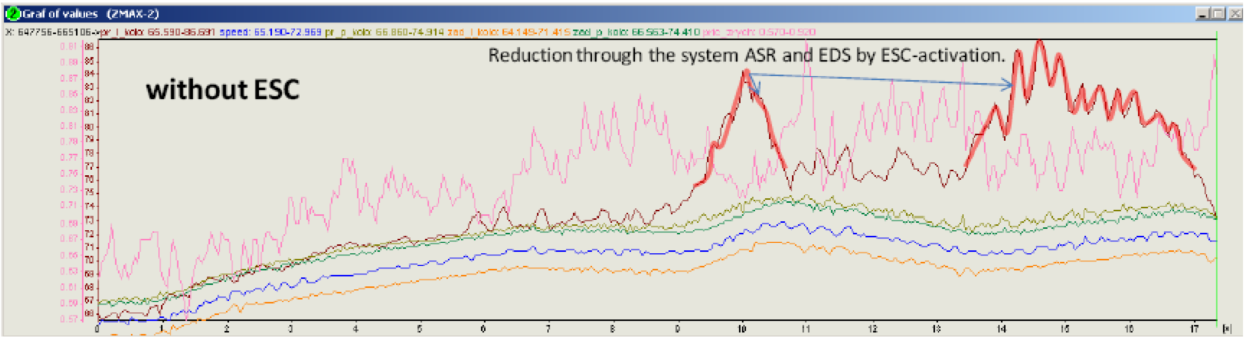
[1]Nedoma, Pavel; [1]Herda, Zdeněk; [2]Plihal, Jiri;
[1]Skoda Auto, Czech Republic; [2]Institute of Information Theory and Automation of the ASCR, Czech Republic

The system ESC (Electronic stability control as well known as ESP Elektronisches Stabilitätsprogramm) of the car "Yeti" comprises several subsystems, above all ABS (Anti-lock Braking System), MSR (Motor-Schleppmoment-Regelung/Engine-Drag torque-Control), ASR (Antrieb-Schlupf-Regelung/Traction-Slip -Control), EDS (Elektronische-Differenzial-Sperre/ Electronic-Differential-Lock) and own ESC. During the driving manoeuvre "Track keeping – circle with radius 50 m" gradually increase lateral acceleration. We tested the vehicle "Yeti" with front wheel drive on dry asphalt with the option - activation/deactivation of the ESC. Due to the increasing lateral force increases tire slip angle, this must be compensated.

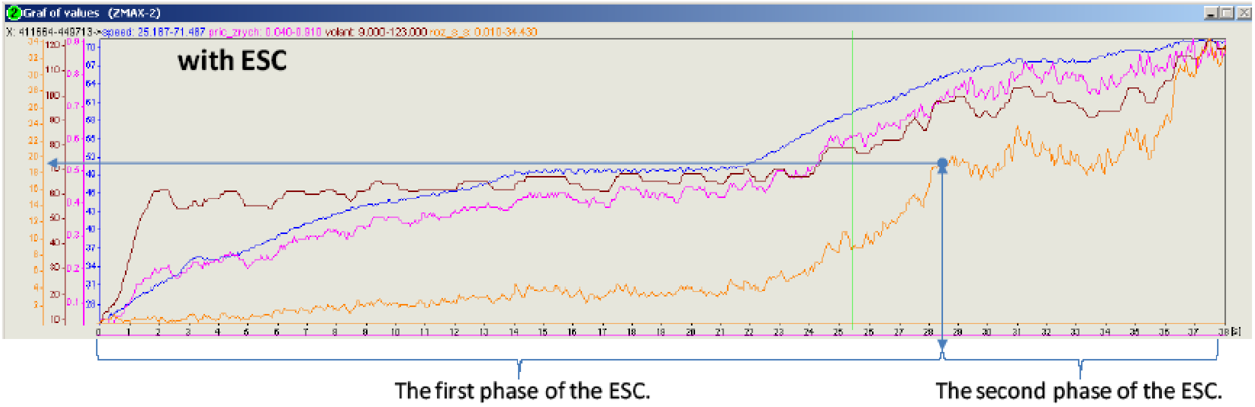
For vehicles without ESC compensation is done just by turning the steering wheel (brown curve in the graph).



On the second graph you can see the spinning of the internal driven front wheels (brown curve in the graph).



Activation ESC reduces the steering angle from 174 degrees to 123 degrees (brown curve in the graph).



On the second graph you can see the reduction of spinning of the internal driven front wheels (brown curve in the graph) through action of the EDS. In the third phase of the regulation could be the speed of rotation of this wheels further decreased.

Self regulation of ESC can be divided, during this test, in three phases. The phases are dependent on the difference between the actual and theoretical yaw speed of the vehicle about a vertical axis. Calculation of the theoretical yaw rate based on the following equation:

$$\omega = \frac{v}{r}$$

v - the immediate middle speed of the vehicle [m/s] (average of speed of rear wheels) ω - the theoretical yaw rate of the vehicle [rad/s] r - theoretical turning radius of the vehicle [m]

The theoretical turning radius of the vehicle based on the following equation:

$$r = \frac{wheel\_base}{\tan \alpha}$$

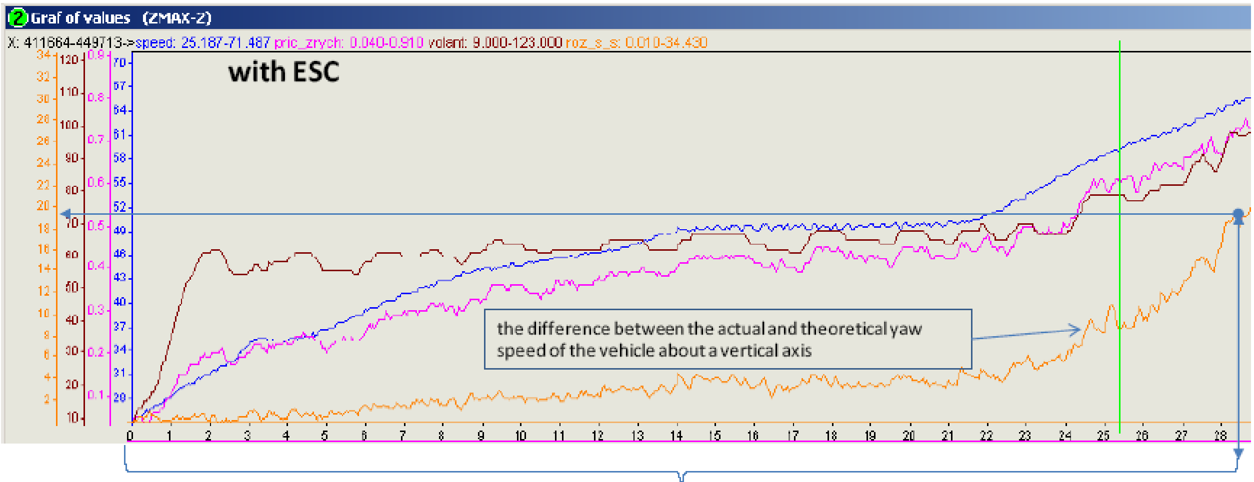
α - average angle of the front wheels [rad] whell_base - wheel base of the car [m] After substitution we get the final relation for the theoretical yaw speed:

$$\omega = \frac{v \cdot \tan\alpha \cdot 180}{wheel\_base \cdot \pi}$$

ω - the theoretical yaw rate of the vehicle [°/s]

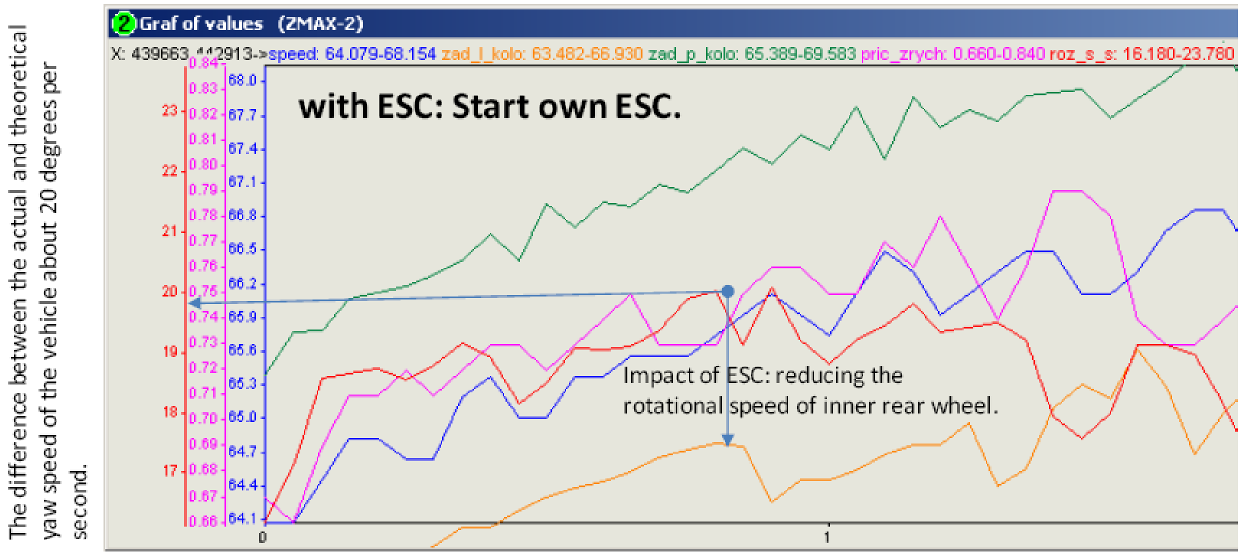
Three phases of EC regulation are as follows:

1. Activation ASR and EDS.



The first phase of the ESC.

2. Activation own ESC - Control the rotational speed of the rear inner wheel.

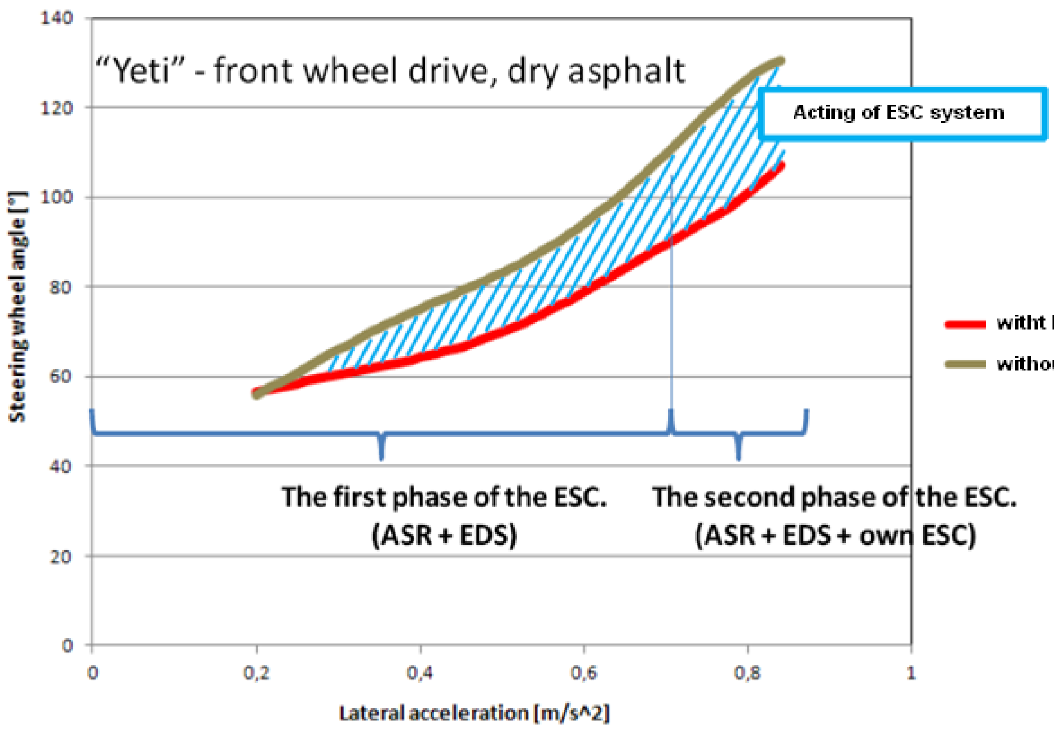


3. Activation own ESC - Control the rotational speed of the front inner wheel. This phase regulation of ESC was not activated during this test. Slowing internal

front driven wheels through differential acceleration causes the outer front wheel driven, which has a beneficial effect.

The following chart shows the first stage of regulation of ESC in the form of the "understeer characteristic".

Comparison with ESC and without ESC is demonstrated on the following picture.

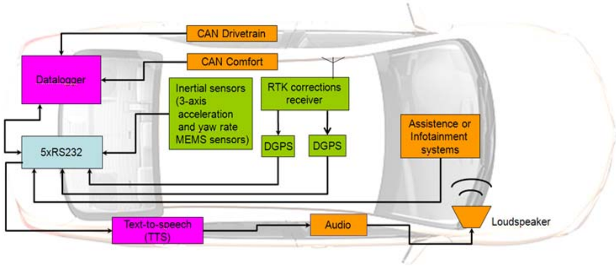


As previously mentioned, the EC system consists of several subsystems that are mutually complementary. Their main objective is holding the vehicle directional stability. At the other vehicle (another drive, another centre of gravity, different weight ...), other road adhesion and external conditions (weather ...), the individual subsystems actions have a different course. Now we are preparing the results of two other driving manoeuvres – „ISO 3888-1 Avoidance test" and "Slalom".

CASE STUDY FOR APPLICATION OF COST FUNCTIONS

One of the alternatives of judgement, how the ESC influenced the stability of car performance with respect to base measured quantities, is the model using so called weight functions. For the purpose of case study, the stability in lateral direction of car motion was tested during the drive on the circle and VDA test. The deviation of yaw rate along axis „z" and lateral acceleration in direction of axis „y" were observed, E_{LAT} consists of these two quantities. The yaw rate along the longitudinal axis of vehicle „x" was also measured.

The demonstration of measurement specification is visualized in following pictures.



The stability in lateral direction (E_{LAT}) is defined by expression inspired by experimental outcomes:

$$E_K = \sum_j w_j \Delta_j$$

Table 1 contains proposed value of parameters:

quantity j	weight w_j
yaw rate along axis „z"	0.7
lateral acceleration in direction of axis „y"	0.3

Table 1: Experimentally designed weight parameters, which characterize the lateral motion of vehicle.

Therefore the stability in lateral direction can be counted by expression:

$$E_{LAT} = 0{,}7\Delta_{\omega n} + 0{,}3\Delta_{al} \ ,$$

where $\Delta_{\omega n}$ is normalized value of difference of measured and counted yaw rate, $\Delta_{\omega n} = \Delta_{\omega}/20$. This normalization brings comparable mean value of differences of both elements. Δ_{al} is absolute value of difference of measured and counted lateral acceleration.

For the interpretation, the maximal values were used, because of their strong impact to the car performance. Each driven manoeuvre was described by following key parameters: maximal value of stability and maximal value of yaw rate along axis „x".

The stability of a car is elementally influenced by the velocity, which the car transits a curve with. Therefore the key parameters were compared with respect to this velocity.

1. The drive on the circle

During this test, a car moved on the circle with constant radius. It increased its velocity, until it left the circular trajectory.

The most important parameter of the test was the velocity, which preceded leaving the circular trajectory. Also, from the record of E_{LAT} is possible to find out the velocity of first unstable behaviour and the maximal value of E_{LAT}.

drive	velocity of the first instability [km/h]	velocity of maximal E_{LAT} [km/h]	value of maximal E_{LAT}
circle s ESC 1	50	70	0,9
circle without ESC 1	43	70	1,2
circle without ESC 1	46	71	1,1
circle with ESC 1	49	71	0,9
circle with ESC - CCW 2	54	75	1,25
circle without ESC - CCW 2	53	75	2
circle with ESC - CCW 1	50	74	0,9
circle without ESC - CCW 1	51	74	2,4

Table 2: the summary of the drives on the circle.

As seen in table 2, the first unstable behaviour appears when the velocity reaches 45 km/h for the car without activated ESC. When the ESC is activated, the first unstable behaviour is observed meanly 3 km/h later. Maximal velocities have values 70 – 75 km/h for both configurations, but the maximal instability during drives without activated ESC is much higher. In two datasets, there is difference in reached velocities caused by different drivers.

2. VDA test

Opposite to the previous test, the velocity during VDA exceeds 100 km/h. It is difficult to model optimal values for these conditions, but the drives with ESC and without it can be recognize by using the values of the yaw rate along longitudinal axis „x".

drive	velocity [km/h]	max. yaw rate along longitudinal axis [°/s]
VDA without ESC 1	109	19,2
VDA without ESC 2	126	18,8
VDA with ESC 1	108	18
VDA with ESC 2	126	16,9

Table 3: the evaluation of VDA.

As seen in table above, the mean value of yaw rate in longitudinal direction is about 10% lower for drives with ESC. However, only limited number of records for each setting was available, therefore the conclusions do not have sufficient explanatory power.

Summary

Presented results describe different methods for the evaluation of car stability in lateral directions. Due to the significant differences between the tests, uniform methodology for recognizing the drives with ESC and without it was not determined. Two different methods for the drive on the circle and VDA were proposed instead.

The stability during the drive on a circle was studied by the model of weight functions E_{LAT}. This model shoved that the first deviation from modelled behaviour came 5 km/h later in case the car has activated the ESC (50 km/h instead of 45 km/h). This phenomenon was observed in statistically limited sample size.

The maximal value of E_{LAT} is the most important quantity, which can significantly identify the drives with ESC. The values derived for the drives without ESC are meanly 50% higher. It implies that the car with ESC behaves more stable in the critical situations.

The presumption, that the instability is accompanied by the significant change of yaw rate along longitudinal axis „x", was posed for WDA test. These differences are 10% higher in case of drive without ESC.

To conclude this work, we can say that proposed model E_{LAT} has statistically significant results, which demonstrate substantial benefit of ESC in the critical situations.

ACKNOWLEDGMENTS

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