

## APPLICATION OF ACTIVE ANTI ROLL BAR SYSTEMS FOR ENCHANCING YAW STABILITY

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ABSTRACT - Nowadays more and more papers are written about Active Anti Roll Bars (AARB). These systems are usually designed for vehicles with high center of gravity, and their purpose is to change the roll stiffness of the vehicle, thus preventing a potential roll-over. In the present paper the use of AARB will be analyzed from a different perspective. An actuator will be presented which allows the proper control of vehicle's yaw stability. First, the basic vehicle dynamic laws are described that show, why and how it is possible to control the handling of the car, with the different stiffness on the front and rear anti roll bars. It is followed by the description of the applied vehicle model, which helps to analyze the effects of the ARB parameters. Simulated tests are presented, that shows how the over- and understeer characteristics of the car vary as the ARB parameters are modified. Finally some basic conclusion are drawn about the applicability of the possible control laws for such system.

### INTRODUCTION

Vehicle Stability Control Systems are very popular nowadays. These systems are using different actuators to control vehicle motion such as four wheel steering, [3] differential braking, [4] etc. The use of the anti roll bars (ARB) for change the vehicle behavior is not a new idea. In racing it is a common technique to change the under- and oversteer behavior of the car at the tire grip limit for a long time [2]. As a control system for passenger cars, this method was not important, because there were no actuators that could change the ARB stiffness. However nowadays some manufacturers came up with such systems, so the investigation of these systems became more important.

### BASIC LAWS OF VEHICLE DYNAMICS

In the following section, vehicle dynamic laws will be presented that makes possible to control the handling behavior of the car, with the different stiffness of the front and rear anti roll bars.

#### Tyre behavior

The behavior and the force production capability of the tyre is a crucial problem when examining vehicle motion. In the followings, the results of Hans B. Pacejka will be used, and the model presented later will use the so called Magic Formula for modeling the tyre behavior. In this section, the basic tyre properties will be described.

Let us consider a single axle of a vehicle, and suppose a normal force ( $F_z$ ), and a lateral force ( $F_{y_{max}}$ ) acting as shown in the free body diagram in the left side of Fig.1. In this situation,

there will be no weight transfer between the wheels, both will have the same slip curve and both of them will produce the same lateral force. Let's consider another situation and suppose, that the lateral force acting over the ground plane, as shown in the right side of Figure 1. In this situation there will be weight transfer between the wheels, and there will be bigger vertical force on the outer tyre, and smaller on the inner one. As a result, the outer tyre will be able to produce more lateral force, and the inner less. Because of the nonlinear degressive  $F_y$  vs.  $F_z$  curve shown at the bottom of Figure 1, the loss on the inner tyre will be bigger than the gain on the outer.

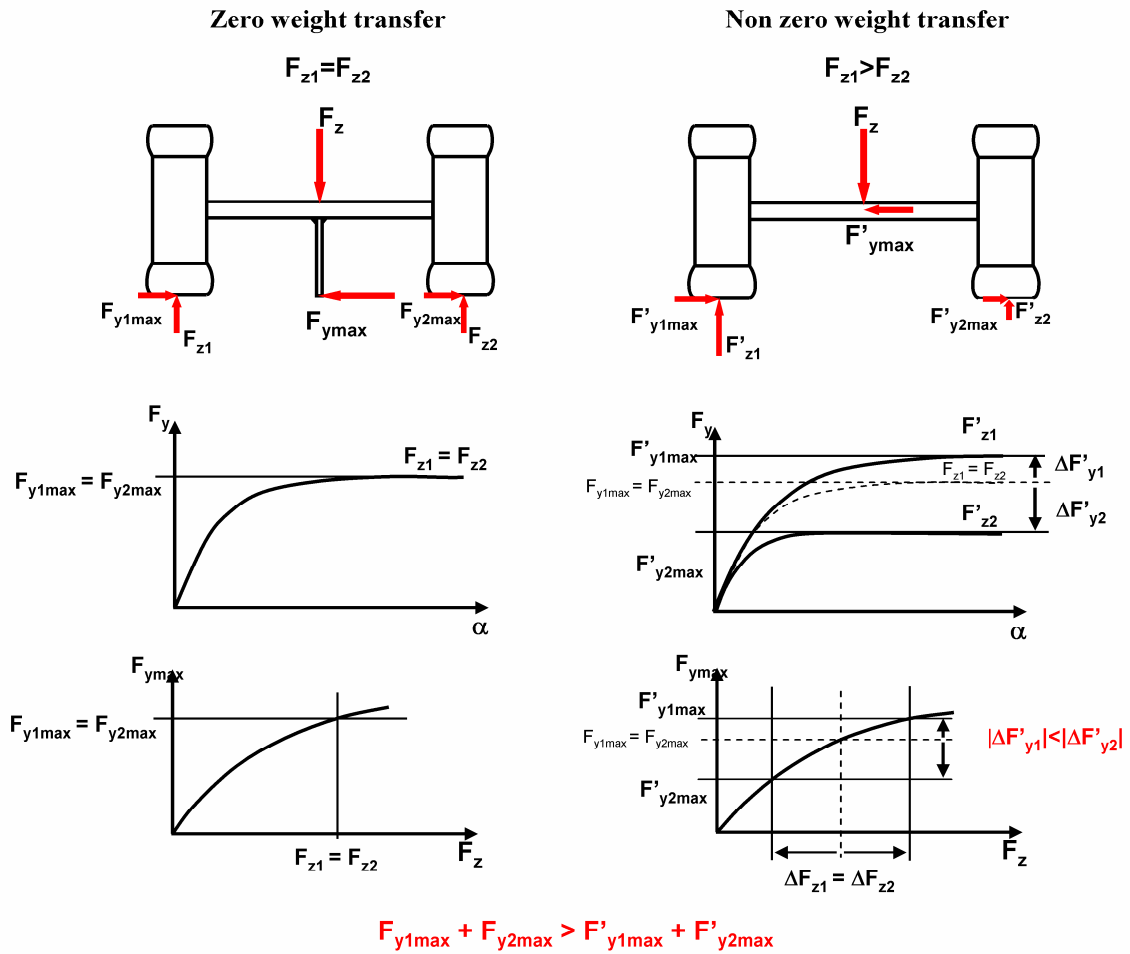


Figure 1: The effect of the weight transfer

The above presented phenomenon will change the effective axle characteristics. The bigger the weight transfer is, the lower the lateral force is on the given axle. The effects of the weight transfer can be seen in Figure 2.

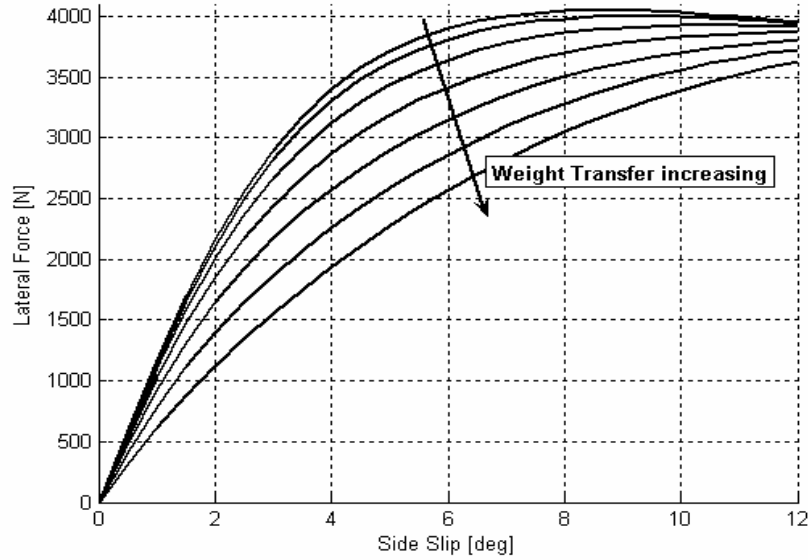


Figure 2 The axle characteristic with increasing weight transfer

The curves depicted in Figure 2 were drawn using the pure lateral slip version of the Magic Formula. The used coefficients correspond to a real tyre, the Goodyear FSAE 20.0x7.0-13 type. The equations of the used model are detailed in [1]. In Figure 2, the highest curve is referring for zero weight transfer, and the lowest is for the situation, when all weight is transferred to the outer wheel. It is clear that at high slip angles the slope of the curves are low, meaning that at high slip angles the side force is not so sensitive for slip angle changes, as at lower slip angles. In addition to this, at the higher slip zones, the side force became very sensitive for weight transfer changes.

### Lateral load transfer distribution

Above it was shown, that the weight transfer on one axle can decrease the available grip, and modify the effective axle characteristic. In this section the way of changing the weight transfer of a given axle will be shown.

According to Pacejka [1] the weight transfer on the axles of the vehicle can be calculated with the following equations:

$$\Delta F_{zi} = \sigma_i m a_y, \quad i = 1 \text{ or } 2 \quad (1)$$

$$\sigma_i = \frac{I}{2s_i} \left( \frac{c_{\phi i}}{c_{\phi 1} + c_{\phi 2} - mgh'} h' + \frac{l - a_i}{l} h_i \right) \quad (2)$$

Where:

$\Delta F_{zi}$	weight transfer on axle $i$
$\sigma_i$	load transfer coefficient of axle $i$
$m$	vehicle mass
$a_y$	lateral acceleration
$s_i$	the half track of axle $i$

$c_{\varphi i}$	Roll stiffness of axle $i$
$h'$	distance of the center of gravity from the roll axis
$h_{1,2}$	height of the front and rear roll centers
$l$	wheelbase
$a_i$	distance of the axle $i$ from the center of gravity

Table 1: Notations

For the sake of better understanding, the quantities given in Table 1 are shown in Figure 3 too. This figure shows a two track vehicle model, that will be used later to create the SimMechanics model of the vehicle.

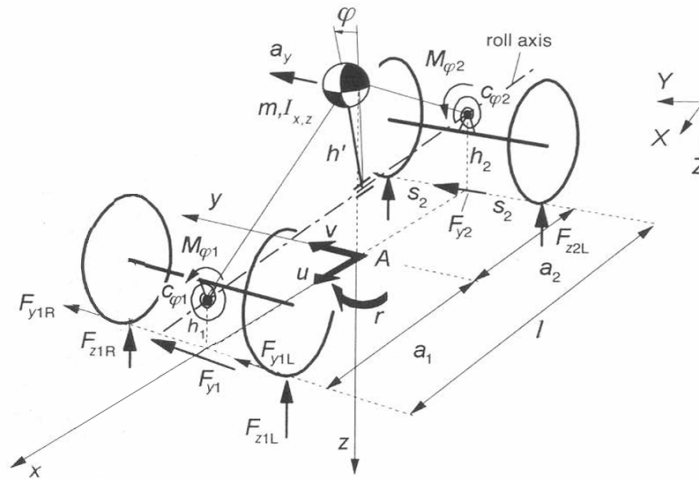


Figure 3: Two track vehicle model

It can be seen in eq(2) that on the axle that has higher roll stiffness ( $c_{\varphi i}$ ) there will be bigger weight transfer, and because of the above mentioned reasons, this will cause lower lateral force too.

With an active anti roll bar ( $M_{\varphi i}$ ) it is possible to change the roll stiffness on an axle, thus changing the weight transfer distribution between the front and rear of the car, meaning that the lateral force produced by the front and rear axles will change too. So this control input can be used to change the lateral behavior of the car. Important to see, that changing the roll stiffness of a given axle will not change the total lateral weight transfer of the vehicle, it will only affect its distribution.

## VEHICLE MODEL

The main objective of the vehicle modeling is to obtain a model which on the one hand represents the dominant dynamics, and on the other hand maintains a low level of model complexity. In the following section a vehicle model is presented, that is capable to deal with the above mentioned phenomena.

### Two track model in SimMechanics

For analyzing the vehicle behavior and the effect of the fore mentioned torque input, a nonlinear two track model was created, using the Matlab/SimMechanics software package. Using the SimMechanics environment has the advantage, that it is not necessary to write the

differential equations of the mechanical system, it is enough to define rigid bodies, and constraints between them. After defining forces acting on such a system, the motion of the bodies is calculated by the software.

The used mechanical model is the same as shown in Figure 3 earlier. It consists of three rigid bodies, one representing the vehicle body and the others the front and rear axles. It also consists of two revolution joints allowing the front and rear axles a rotational degree of freedom around the roll axis relative to the vehicle body. The additional torque input to the suspension also can be seen in the figure ( $M_{\phi_i}$ )

The forces acting on the vehicle are generated by the tyre. For tyre modeling, the same Magic Formula was used which was used for defining the axle characteristics earlier. Since we are dealing with the lateral dynamics of the vehicle, the pure lateral slip form of the Magic Formula was used. The longitudinal behavior of the tyre was not modeled and the forces causing forward motion of the vehicle were put directly on the rear wheels. The structure of the obtained SimMechanics model can be seen in Figure 4

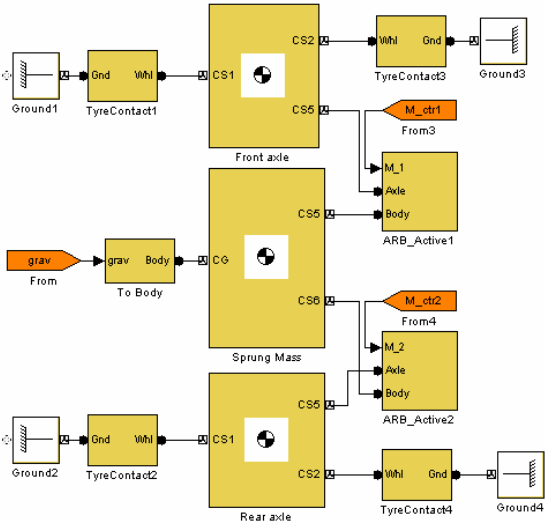


Figure 4.: The SimMechanics model

The final model has the inputs as the longitudinal forces acting on the rear tyres, the steering angle of the front wheels, and the additional torques in the front and rear suspension. The output is the motion of the vehicle including all degrees of freedom.

Driver model

The driver model used in this work was very simple. The only function was to keep the vehicle speed at a desired value by changing the longitudinal force, acting on the rear axle. For this purpose a simple PI controller was used.

Simulation results

Tests were made to analyze the vehicle behavior near the tyre grip limit. The model parameters used for the tests are summarized in Table 2.

$m$	300	kg	Vehicle mass
$J_{zz}$	160	$kgm^2$	Vehicle moment of inertia around z axis
$s_1$	0.6	m	The half track of front axle
$s_2$	0.6	m	The half track of rear axle
$c_{\phi 1}$	200	Nm/deg	Roll stiffness of front axle
$c_{\phi 2}$	200	Nm/deg	Roll stiffness of rear axle
$h'$	0.25	m	distance of the center of gravity from the roll axis
$h_1$	0.06	m	height of the front roll center
$h_2$	0.06	m	height of the rear roll center
$a_1$	0.8	m	distance of the front axle from the center of gravity
$a_2$	0.8	m	distance of the rear axle from the center of gravity

Table 2.: Model parameters

In the followings one test will be presented, that shows the effect of the varying weight transfer on the front and rear axles. The vehicle is running on a flat road, with a constant speed, and constant steer angle. In this steady state condition, suddenly the lateral load transfer distribution is changed by changing the stiffness of the anti roll bars. The vehicle response in this situation can be seen in Figure 5.

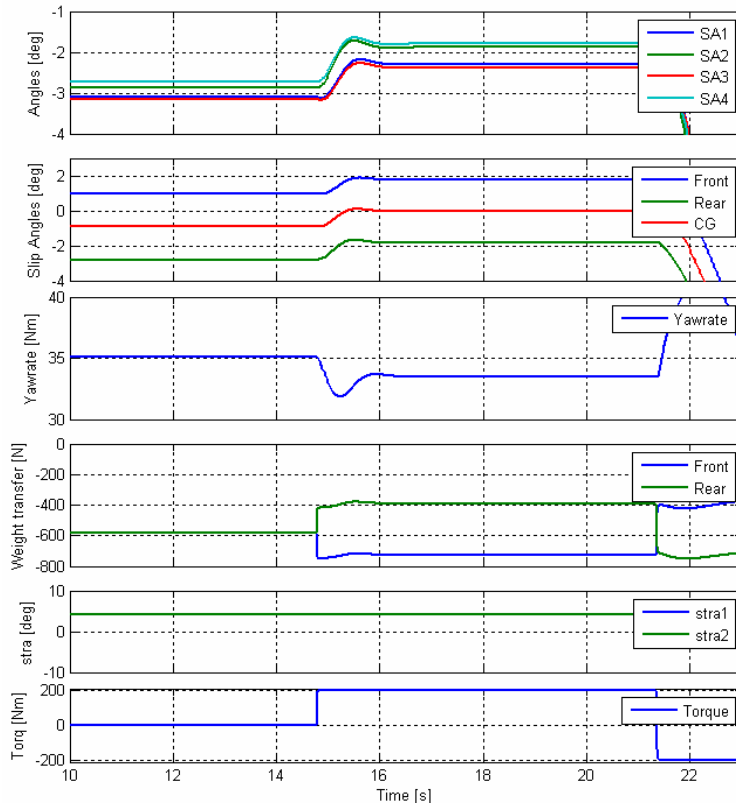


Figure 5.: Test results

In Figure 5 the results of the simulation can be seen. Looking from the top to the bottom, on the first plot the slip angle of the wheels can be seen, where SA1 corresponds to the front left tyre, SA2 to the rear left, and SA3, SA4 to the front and rear right tyres respectively. On the second plot the slip angles at the front and rear axles and at the center of gravity can be seen,

while the following plots shows the yaw rate of the vehicle, the weight transfer on the axles, and the steer angles on the front left and right tyres,  $\text{stra1}$  and  $\text{stra2}$  respectively. In the last plot the input torque is depicted, which is used to change the stiffness of the anti roll bar.

In Figure 5 three phases of the curves can be seen. First there is no additional torque at the anti roll bars, so the stiffness is equal. The vehicle is running in a steady state condition with constant yaw rate and constant slip angles. Since the front and rear ends are the same, the weight transfer on the front and rear axles are equal.

In the second phase, the additional torque input is applied, causing an increase in front weight transfer and decrease the rear (thus changing the axle characteristics) so induce a different steady state condition. The increasing front weight transfer causes decreasing force production capability on the front, while the decreasing rear weight transfer means increased grip in the rear, so the vehicle tends to a more understeer behavior, as shown by the decreased yaw rate and body slip angle.

In the third phase of the test, the weight transfer on the front and rear is changed, by applying an opposite torque at the ARB-s. According to the ideas before, in this situation the rear end will loose grip, and the vehicle will become unstable, as the diverging body slip angle and the yaw rate indicating it.

## POSSIBLE CONTROL LAWS

For yaw control with AARB, in [5] the use of a simple PI controller is presented. Although it is not a modern control law the presented controlled performed well. Using PI control strategy also has the advantage that it doesn't need high computational performance, and it is not necessary to construct complicated models. On the other hand the need for better controller performance drives us to model based controllers.

In [3] the control law virtual model following control was used to control the rear wheel steering of a 4WS car. The virtual model following control seems to be an adequate control law for vehicle controls because of its good following properties and robustness. The problems with this strategy can be the appropriate vehicle model, and the computational needs.

As it was mentioned earlier, the yaw control of the vehicle through changing the lateral weight transfer distribution is mostly effective at high lateral acceleration, near the tyre grip limit. In this slip zone the tyres show nonlinear behavior so it is important to analyze the possible nonlinear vehicle models and nonlinear control methods too.

Detailed analysis of the models for control purposes will be the subject of future works

## REFERENCE

- (1) Hans B. Pacejka, „Tire and Vehicle Dynamics” (Hardcover) p. 627 Society of Automotive Engineers Inc (October 2002) ISBN-10: 0768011264 ISBN-13: 978-0768011265
- (2) Milliken, W. F., Milliken, D. L. „Race Car Vehicle Dynamics” (Hardcover) p. 993, SAE International (August 1995), ISBN-10: 1560915269 ISBN-13: 978-1560915263
- (3) Palkovics, L., „Effect of the Controller Parameters on the Steerability of the Four Wheel Steered Car”, Vehicle System Dynamics, 21, pp. 109-128, 1992
- (4) Zhao, C., Xiang, W., Richardson, P., „Vehicle Lateral Control and Yaw Stability Control through Differential Braking” Industrial Electronics, 2006 IEEE International Symposium, pp. 384-389, 2006
- (5) Manssouri, K. Integrated Motion Control of an Overactuated Vehicle Master Thesis, Technical University Eindhoven, Department of Mechanical Engineering, Dynamics and Control Group, 2004