SIMULATION OF VEHICLE DYNAMICS OF A QUAD WITH ACTIVE DRIVER

Electrified traction drives allow today to equip quads with individual axle drives in the fields of leisure and forest operation. But to assure the function of these all-terrain vehicles (ATV) especially the higher ratio between the mass of the driver to the mass of the vehicle has to be taken into account. Gigatronik simulated the vehicle dynamics using an active driver model in order to increase safety and to parameterise a torque vectoring function.

AUTHORS

M. SC. FABIAN JANSEN
is studied physicist and employee in the Department for Modelling and Simulation at Gigatronik in Stuttgart (Germany).

M. ING. ISMAIL GÖCER
wrote his master thesis about vehicle dynamics simulations at Gigatronik in Stuttgart (Germany).

MOTION OF THE DRIVER

As a side effect of having a vehicle with electrified drive one has to develop new powertrain concepts. One way would be to fit each wheel with its own electric motor and control it individually. This allows implementing new functions to improve driving comfort and to save energy.

Gigatronik describes here the parameterisation and simulation of the dynamics of a modified quad (all-terrain vehicle, ATV) that was converted to an electric vehicle with individual motors at each wheel. With the created model it is possible to test and optimise new functions even before the vehicle exists. A special focus is put on simulating a realistic behaviour for the driver. This is because the ratio between the mass of the driver to the mass of the vehicle is much higher in a quad than in a passenger car. The proper motion of the driver has a big influence on the driving behaviour of the quad. As an example for the implementation and parameterisation of a function a torque vectoring feature is implemented.

First the simulation environment is presented, followed by the driver model and its influence on the vehicle dynamics. Then the torque vectoring is described and parameterised.

SIMULATION ENVIRONMENT

The vehicle dynamics simulations were performed with CarMaker [1] by IPG. Additionally to the provided model parts CarMaker for Simulink was used to model the powertrain and the driver behaviour.

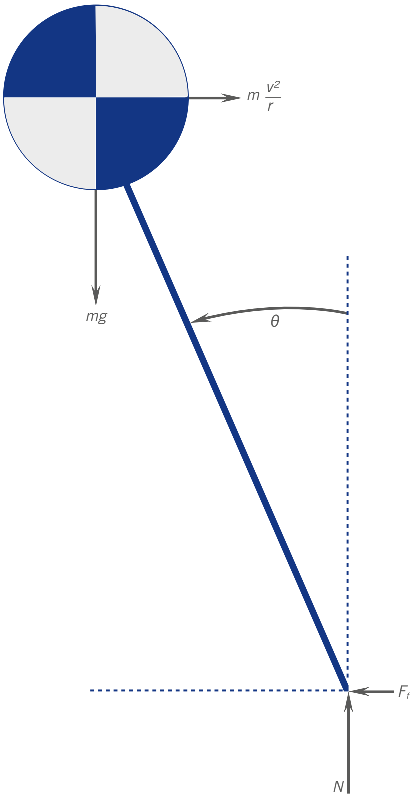
The model was based on a quad with individual electrical motors which is developed at Gigatronik in Stuttgart as a study and prototype. For this the Simulink interface was created in such a way that the control modules that were created for the quad using model based design can be used in the simulation without modifications.

MODELLING THE DRIVER

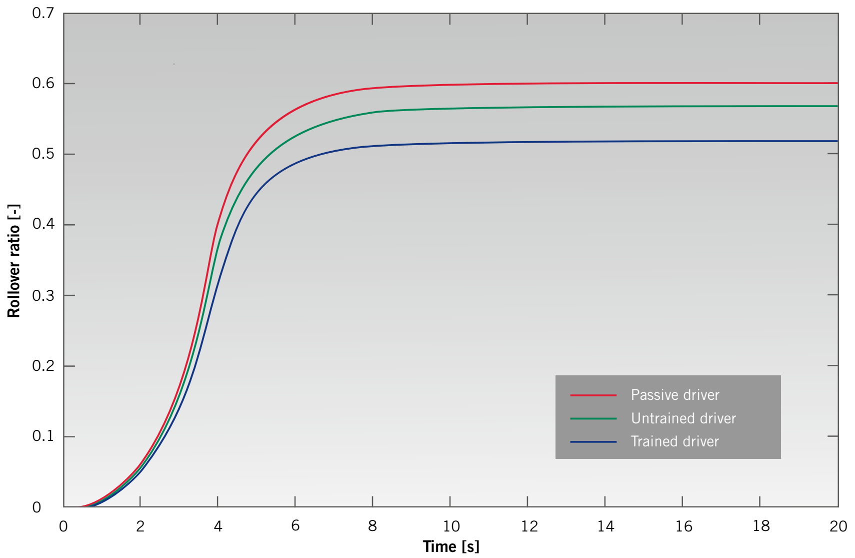
The behaviour of a quad driver is similar to the behaviour of a motorcycle driver when cornering. The motorcycle driver leans into the corner in order to balance the centrifugal force with the angle movement θ and to avoid tipping over, see ❶ as well as Eq. 1 (see box). A vehicle with four wheels like a quad is not as likely to rollover; here going around a corner will first change the weight distribution between the inner and outer wheels before a rollover sets in. With a quad the percentage of the driver of the total mass is over 20 %. The driver is positioned very high so the centre of gravity will change considerably when the driver moves. Because the centre of gravity is also very high a rollover is more likely to take place, which means the driver has to perform active stabilisation motions. Additionally the driver can change the weight distribution in order to improve traction.

In the model designed, the driver consists of two masses: the moving upper body and the stationary legs. Both are modelled as external loads in CarMaker. The upper body can move like an inverted pendulum fixed on the seat, this motion is described by yaw, roll and pitch angles.

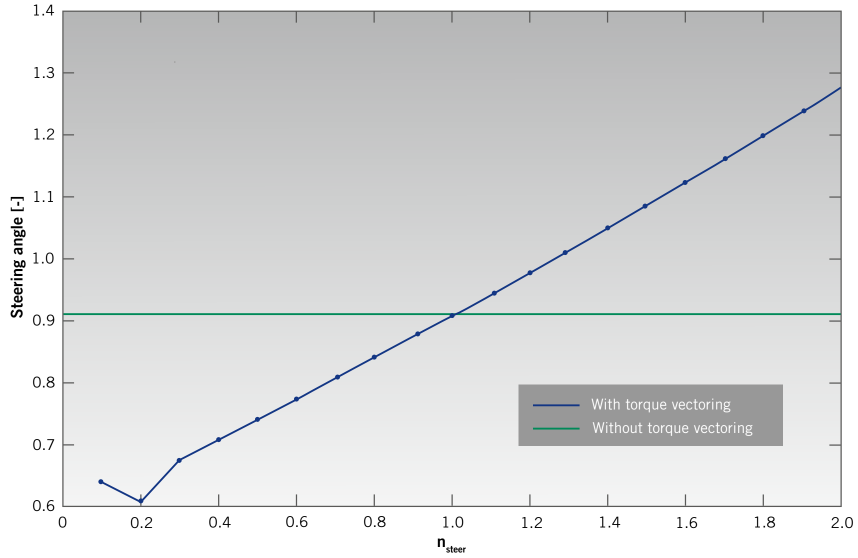
The implemented strategy of the driver is to compensate accelerations. This is done orthogonal to the direction of



❶ Movement θ of a motorcycle driver (mass mg) to compensate the lateral acceleration caused by driving around a corner



❷ Comparison between the rollover ratio τ of three drivers going through a corner with constant accelator pedal position – the passive driver is closest to a rollover, followed by the untrained and then the trained active driver



❸ Dependency of the steering angle on the application factor n_{steer} – additionally the required angle without torque vectoring is shown

motion to avoid roll and parallel to the direction of motion to improve traction. A non-horizontal vehicle position is also interpreted as an acceleration to avoid tipping on steep terrain. To differentiate between an inexperienced and an experienced driver the strength of the balancing motion is varied. The inexperienced driver leans just like a motorcycle driver just enough as his body weight requires while the experienced driver is correcting for the higher vehicle mass and leans much more aggressively.

DRIVING SCENARIOS AND MODEL VALIDATION

The quad was tested in different driving scenarios to see the effect of the active driver and the torque vectoring on longitudinal and lateral dynamics. For this the individual functions were selectively activated. When the driver is not active he was substituted by a mass with fixed position. When the torque vectoring is not enabled each wheel is driven with the same torque without adapting to the turning radius or the axle load distribution. To achieve comparable results the acceleration request is kept the same for all test runs.

To validate the driver model the roll angle of the vehicle was assessed for the different driver motions when cornering. In order to do this the rollover ratio τ was defined as in Eq. 2. This ratio can be used to indicate the loss of ground contact. As long as the vertical forces are equal on both sides the indicator is 0. It reaches the value 1 when the vertical force on one side is 0, at which point the rollover sets in.

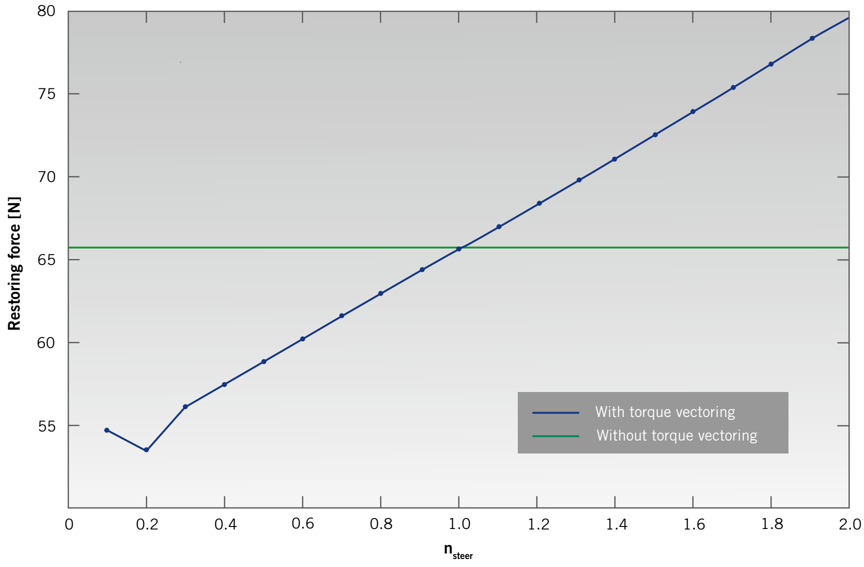
Under these conditions the test was executed with an experienced active, an inexperienced active and a passive driver with a weight of 80 kg. The results are shown in ❷. It is clear that even the inexperienced driver is much less prone to rollover than the static driver. This shows how important it is to include the driver behaviour when simulating the vehicle dynamics of a quad.

TORQUE VECTORING

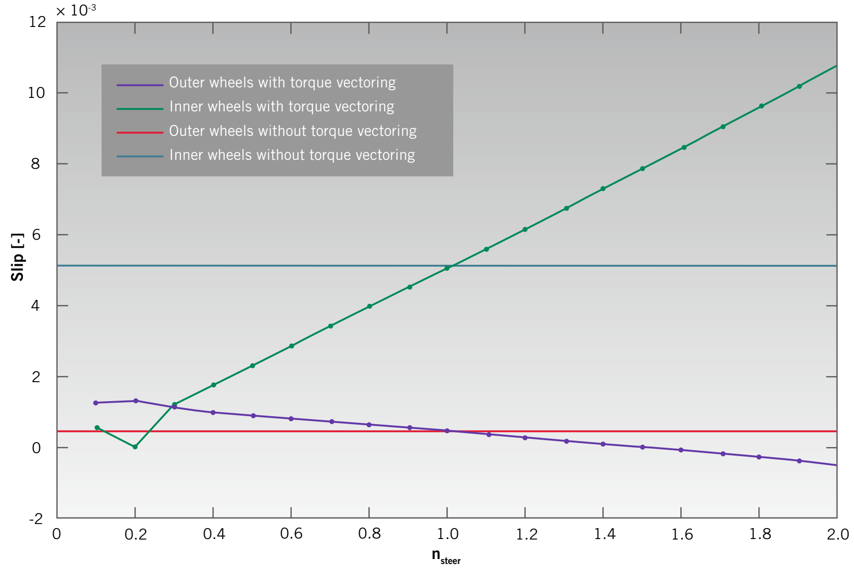
A torque vectoring algorithm was implemented to control the propulsion of the quad. This function is distributing the requested total torque on the single wheels connected to the individual electric motor. The accurate model is shown in [2]. It was integrated into CarMaker using the Simulink interface. CarMaker gets the wheel torques from the torque vectoring algorithm and passes back the wheel speeds.

The algorithm distributes the torques according to the axle load distribution and the steering angle. These are incorporated in the calculation of the Eq. 3 via the relative factors k_f, k_r, k_{si} and k_{so}. The factors for the axle loads are derived by normalising the vertical axle forces on the front (k_f) and rear (k_r). The inner and outer steering angle factors k_{si} and k_{so} depend on the different radii travelled by the inner (r_i) and outer (r_o) wheels. They are calculated from the geometrical parameters wheelbase, trackwidth and steering angle.

As in reality the inner and outer factors only slightly differ an additional application factor n_{steer} was used, the so-called trim parameter. The calculation of the factors is shown in Eq. 4. By changing the trim parameter the algorithm can be tuned to behave more aggressively (small values; $0 < n_{steer} < 1$), cautiously



❹ Dependency of the restoring force on the application factor n_{steer} – additionally the force without torque vectoring is shown



❺ Slip at the outer and inner wheels depending on the application factor n_{steer}

($n_{steer} \approx 1$) or even counter productively ($n_{steer} > 1$). The effect of this trim parameter was extensively studied in the performed simulation runs; the results are shown in the following section.

TEST RESULTS

Several test cases were defined to study the influence of the trim parameter on vehicle dynamics. The first one is the same as the set-up used to show the influence of the driver's behaviour. Therefore, the vehicle is going around a circle with constant acceleration pedal position and cornering radius.

The results are shown in ❸ and ❹. The performance of the simulation without torque vectoring is shown as a horizontal line, additionally the performance for different values for n_{steer} is shown. The analysed values are the steering angle required to achieve the same turning radius at the same speed and the restoring force the driver has to counter to achieve this steering angle. One can easily see that distributing more torque to the outer wheels results in a smaller steering angle and a smaller restoring force. The torque vectoring function can therefore be used as a power steering; the vehicle actively supports steering into a corner. When the intervention gets too strong (small n_{steer}) the system becomes unstable.

A general effect of the torque vectoring is that the dynamically distributed torque reduces wheel slip, ❺. Without torque vectoring the inner wheels have a much higher slip than the outer wheels. The stronger the torque vectoring intervenes the smaller the slip of the inner wheels gets, this causes the effects described before.

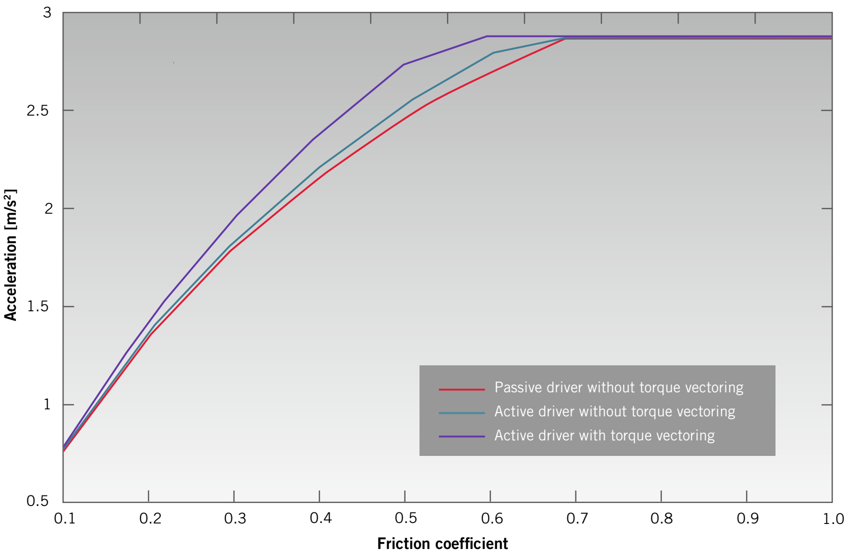
A second test case was an acceleration from zero velocity with constant acceleration pedal position and therefore constant total torque, but different friction coefficients. The acceleration achieved with active driver with and without torque vectoring as well as without active driver and without torque vectoring is shown in ❻. In this setup the active driver and the torque vectoring decrease the slip, improving the transfer of force on the road and therefore increase the acceleration. Very small friction coefficients lead to wheelspin, so the effect of the torque vectoring is not very pronounced. However, for medium friction coefficients the torque vectoring can prevent wheelspin completely, leading to a significantly higher acceleration.

CONCLUSION

In this work Gigatronik describes the implementation of a simple torque vectoring algorithm and of an active driver model. The simulation tool CarMaker by IPG is used in this study. The additional models are integrated using CarMaker for Simulink. The simulation results are also collected and analysed using Simulink. The CarMaker test manager was very useful for automated batch testing.

The active driver is modelled as an inverted pendulum mounted on the quad. The angles are set depending on the longitudinal and lateral acceleration of the vehicle.

The torque vectoring algorithm distributes the total torque on the four wheels intelligently. For this it evaluates the vehicle acceleration as well as the steering angle. The presented influences of the active driver model punctuate its importance.



❻ Dependence of the acceleration on the friction coefficient

It is shown that the driver model significantly influences the rollover tendency of the vehicle. Further on it was clear that the accessible longitudinal acceleration on a slippery road is influenced by the driver. A correctly parameterised torque vectoring algorithm supports the driveability in corners and also improves longitudinal dynamics. The results presented here also show clearly that it is possible to analyse new powertrain functionality before implementing it in a real vehicle.

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[1] IPG Automotive GmbH: Simulation Solutions / CarMaker. In: www.ipg.de, as at 18 September 2013

[2] Klingenstein, F.: Design der Softwarearchitektur und Implementierung des Drehmomentpfades für ein Elektro-Quad. Bachelor Thesis, Esslingen, University of Applied Sciences Esslingen, 2013

EQ. 1

$$\tan(\theta) = \frac{v^2/r}{g} = \frac{a_y}{g}$$

EQ. 2

$$\tau = \left| \frac{Fz_{\mathrm{right}} - Fz_{\mathrm{left}}}{Fz_{\mathrm{right}} + Fz_{\mathrm{left}}} \right|$$

EQ. 3

$$\begin{aligned} M_{front,inner} &= M_{desire} \cdot k_f \cdot k_{si} \\ M_{front,outer} &= M_{desire} \cdot k_f \cdot k_{so} \\ M_{rear,inner} &= M_{desire} \cdot k_r \cdot k_{si} \\ M_{rear,outer} &= M_{desire} \cdot k_r \cdot k_{so} \end{aligned}$$

EQ. 4

$$k_f = 0.5 + \frac{F_{z,front}}{m_{Quad} \cdot g}$$

$$k_r = 0.5 + \frac{F_{z,rear}}{m_{Quad} \cdot g}$$

$$k_{si} = n_{steer} \cdot \frac{r_i}{r_o}$$

$$k_{so} = 2 - k_{si}$$

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About the Author

He has worked together with international partners to offer numerous seminars preparing students for construction projects abroad.

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