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Identification of Rider-Vehicle Coupling on Motorcycles and Riding Simulators

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ABSTRACT

The rider of a motorcycle must stabilize the capsize mode especially at low speeds through correct rider actions, consisting of both steering and leaning inputs. With decreasing vehicle speeds, the relevance of rider body motion increases. This becomes crucial considering high fidelity motorcycle simulators. In order to improve the presence on a dynamic motorcycle riding simulator, it is recommended to validly implement rider-vehicle-coupling capabilities to the simulator architecture instead of utilizing solely the steering as input to the vehicle dynamics model. In the present study, the DESMORI Simulator [1] is used, that is equipped with a measurement system that senses the rider induced roll torque. However, measuring this physical entity in real life riding scenarios is almost impossible, as no holistic approach is known to measure all forces and torques between any contact points of the rider with the vehicle (i.e. 6-DOF foot pegs, 6-DOF saddle, knee-pressure mat, vertical handlebar forces, etc.). Thus, an optical measurement system is used to compare the rider behaviour between real riding scenarios and simulator testing.

The goal of this study is to gain further knowledge about the coupling effects between rider and vehicle and to use this knowledge to improve the controllability of the DESMORI simulator through valid implementation of the coupling forces in the vehicle dynamics model. Therefore, in a first step, dynamic parameters of a rider are measured via synthetic motion excitation of the simulator platform and steering while measuring e.g. the rider roll and steer torques and positions respectively. The rider then performs test manoeuvers on the measurement motorcycle while being exposed to roll torque disturbances. The manoeuvers are re-enacted on the simulator to provoke similar body responses.

The study shows a strong coupling from steering excitations to an additional roll-torque through the rider's upper body. The coupling into the other direction is less significant, because of the flexibility of hip and torso. A different behaviour between closed- and open-loop motorcycle-simulator riding was noticeable, that has to be taken into account for further rider-parameter-investigations.

Keywords: motorcycle simulator, rider behavior, rider motion, validation.

1 INTRODUCTION

Simulators are widely spread in automotive industry, but not that much in motorcycle applications. One reason for this might result from a lack of naturalness and rideability that is still immanent to many motorcycle simulators. Our approach to improve the rideability of a dynamic motorcycle riding simulator is to utilize rider motion as an input to increase the presence of the simulator. In project DESMORI, a simulator was designed and built that uses roll-torque-determination to measure the control input that comes from changing the rider's posture. Therefore, a platform-motion-compensation model is used that considers the rider as rigid point mass model. With the use of roll-torque-determination and steer torque sensor, the simulator can be controlled by steering and leaning motions and provides feedback on both cues, as shown in figure 1.

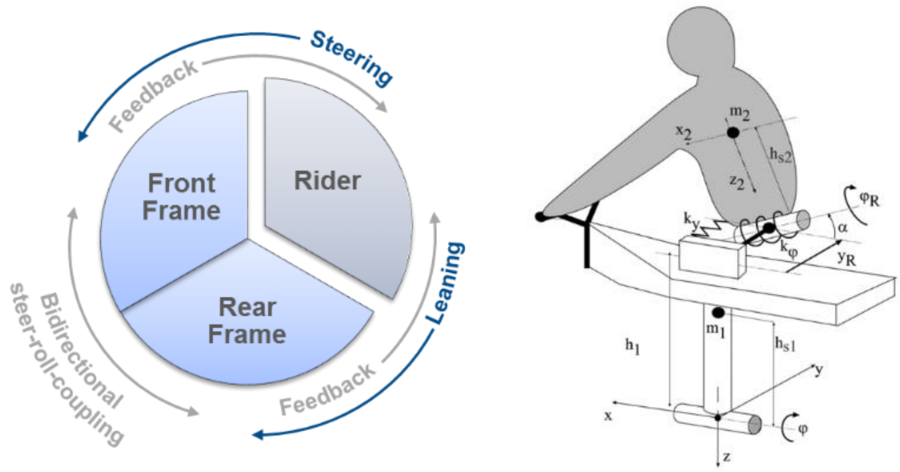

Figure 1. Coupling effects between rider and vehicle (Right picture: cf. [2])

In the past, we investigated the rider's coupling with the front frame by means of steering, the coupling between rider body and rear frame by means of leaning and the bidirectional steer-roll-coupling by means of vehicle dynamics (i.e. gyroscopic effect) separately. The aim of this paper is to further investigate a bidirectional steer-roll-coupling not through vehicle dynamics but through the rider's body.

Rider-body-excitations through roll motions of the vehicle will possibly result in unwanted steering motions and vice versa. Therefore, there should be a measurable coupling between excitations on steering and rolling of the simulator. What is still unknown is the amplitude of such coupling forces between roll- and steer excitations. All this depends a lot on active or passive muscle tension of a human body, what means there should be a difference observable between different active and passive rider configurations.

The results of these investigations shall be used to improve the platform-motion-compensation model as well as gathering knowledge on rider impedance properties, which recently have become a matter of interest also in other research groups [3].

2 METHODOLOGY

To investigate if and how the rider's impedance properties influence both simulator and vehicle we perform experiments in both environments, where external, defined disturbances act on the rider. The DESMORI simulator is a versatile tool that allows for multiple test designs. For example, both open loop (e.g. defined platform motion with a "passive" rider) and closed loop (e.g. online simulator riding with an "active" rider) investigations can be performed. This is in contrast to testing on the real motorcycle, where open loop testing obviously is not possible.

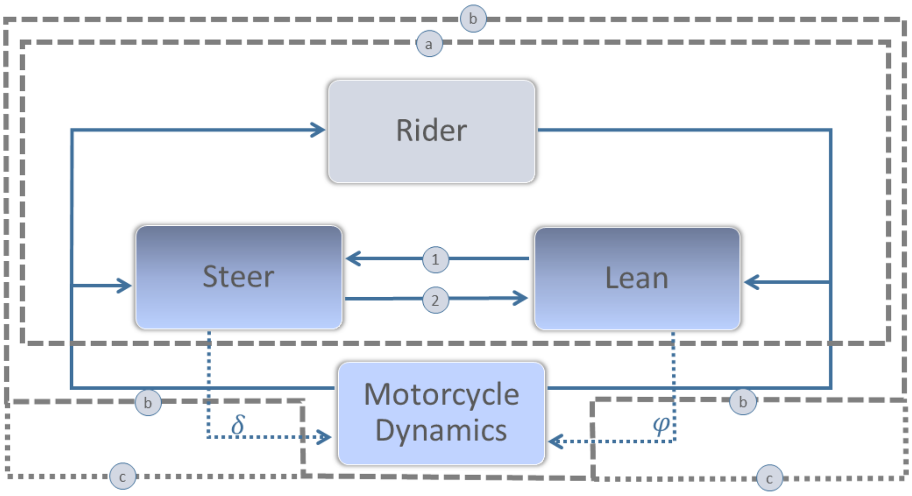

Figure 2. Coupling of rider and motorcycle through steer and lean

For a better understanding of the coupling mechanisms between rider and motorcycle, they are shown in figure 2. The part without rider represents the mentioned bidirectional steer-roll-coupling through motorcycle dynamics, which is already known. The focus of this paper is a better understanding of the other coupling effects between steer- and roll/lean-mechanisms through the rider's body.

Focusing on the rider, there exist two different ways of coupling, that need to be considered separately. On the one hand there is the coupling of steering motions leading to a leaning of the rider (figure 2, ②). Forces are induced into the rider's upper body through hands and arms and might lead to an additional torque around the roll-axes. This effect can be compared with a pothole crossing, during a cornering maneuver.

On the other hand, a roll motion of the motorcycle will trigger a leaning of the rider and thus again through upper body, arms and hands, a coupling into the steering (figure 2, ①). What is still unknown, is the amount of the coupling effects, and if they need to be taken into account for the rider model on the dynamic simulator.

Table 1. Possible Investigation Methods

	Simulator			**Motorcycle**
Configuration	Defined Motion	Open loop Scenario	Closed loop Scenario	Closed loop Scenario
Excitation	φ_{hex}	$\Delta\varphi_{\text{hex}}$	ΔT_x	ΔT_x
	δ_{mock}	$\Delta\delta_{\text{mock}}$	ΔT_δ	-

The possible investigation methods are listed in table 1. The simplest way to excite the rider is by applying defined motions – especially hexapod roll motion φ_{hex} and mockup steer angle δ_{mock} respectively. For identifying rider behavior, typical excitations known from system identification methods (impulse, step function, saw tooth, sweep, etc.) might be used. Additionally, for the identification, investigations without the influence of motorcycle dynamics are useful (figure 2, a). While this method provides the highest variability, it is also the most "artificial" one. The rider might e.g. just sit on the saddle with no body tension rather than being actively involved in a dynamic scenario.

Therefore, an open loop scenario can be performed, where the rider experiences a dynamic motorcycle ride as if he was a passenger on a self-riding simulator (figure 2, b). While this method still provides full control over the dynamic states of the simulator and its excitation, it might increase the rider's involvement and thus his body tension. As the scenario already demand certain roll and steer angles respectively, the excitation is denoted as difference $\Delta\varphi, \delta$.

Closed loop scenarios provide the highest involvement as the rider must control the vehicle himself (figure 2, c). Thus, they are supposed to provide the most valid measurements of the rider behavior. However, they are the least controlled method and disturbances in roll or steer angles might destabilize the ride to a non-controllable degree. In order to maintain controllability for the rider, the excitations must not concern the angles but torques around the respective axis. This guarantees steady changing rates of the steer and roll axis and enables superposing by the rider's inputs.

On the real motorcycle, external excitation is again only feasible by torques rather than angles. For this study however we only implemented a device for roll torque actuation but no steering actuation.

This paper will concentrate on the defined motion configuration as well as the two closed loop scenario configurations. The experiments are performed on the DESMORI Simulator at WIVW and at the August-Euler-Airfield at TU Darmstadt. For now, only expert riders were involved in the study.

3 MEASUREMENT EQUIPMENT

For the described study, we use the DESMORI Simulator that has been developed in collaboration of WIVW, BMW Motorrad and FZD in 2014 and is subject to updates and revisions throughout various projects. For the real road tests, we use a Honda NC 700 X available at FZD. Both simulator and motorcycle are described in more detail in the following:

3.1 The DESMORI Motorcycle Simulator

The goal of project DESMORI was to develop a tool capable of investigating human machine interfaces on motorcycles. The result was the DESMORI simulator, depicted below:

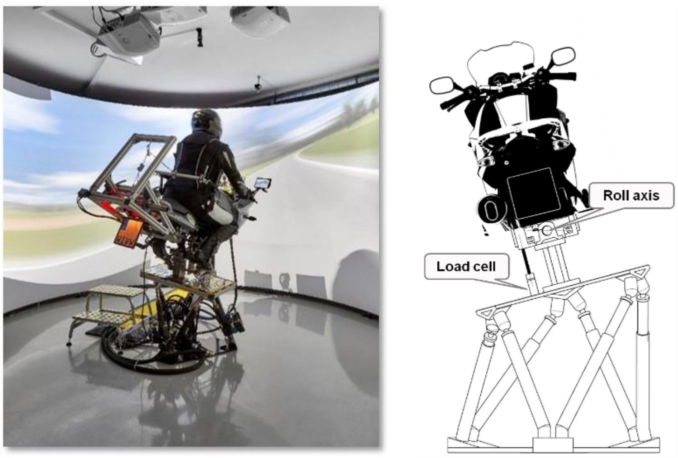

Figure 3. The DESMORI simulator. Stewart platform for motion simulation, cylindrical projection, rope-towing mechanism for longitudinal dynamic simulation. Roll axis (right)

The simulator consists of a hydraulic 6-DoF Stewart platform (Hexapod) that stands in the centre of a cylindrical screen of diameter and height 4.5 m x 3 m with a horizontal field of view of 220°.

TFT displays substitute the rear mirrors and cockpit. Headphones implemented into a helmet provide auditive cues. The helmet also serves to reduce the rider's field of view and reduces distracting inputs (i.e. if the rider would see the border of the projection screen, reminding him of being in a laboratory environment). The last but not least rider feedback system is a rope towing mechanism acting in the vehicle's longitudinal direction to provide proprioceptive cues to the rider when braking or accelerating or simulating drag forces.

With these feedback cues (visual, auditive, vestibular, proprioceptive) the rider is capable to experience the virtual scenario that is provided by WIVW in-house software SILAB. There, all hardware and software modules are interconnected and synchronized. Among these modules is the vehicle dynamics module, which is realized in Matlab/Simulink. The module is based on a VI-grade BikeRealTime Co-Simulation and includes various controls and the motion cueing algorithm (MCA) as well.

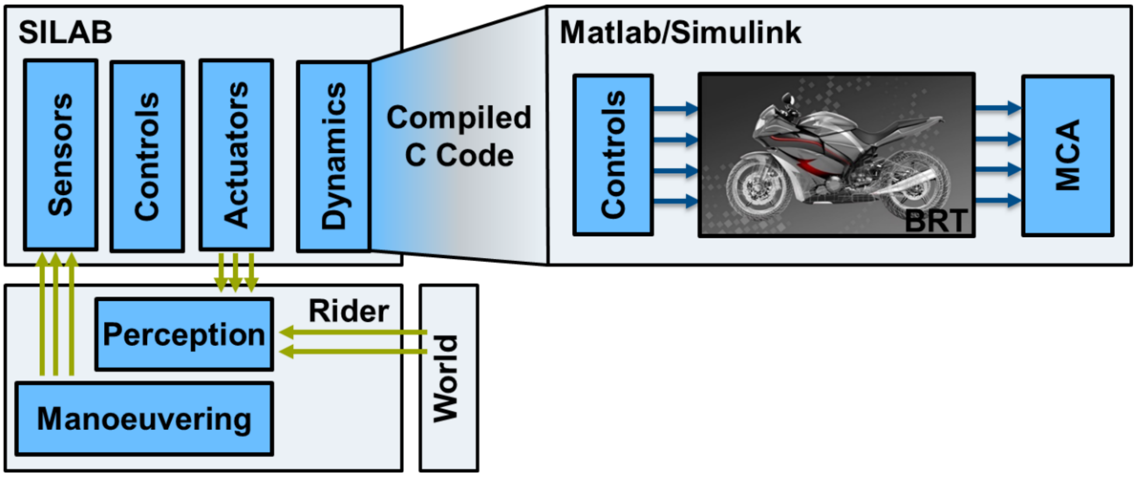

Figure 4. System architecture of the DESMORI Simulator

The rider can influence the provided virtual system through any input he would expect from a real motorcycle, namely the throttle, clutch, front and rear brake, steering and leaning motion. The latter one is measured through a mechatronic setup that determines the rider induced roll torque. In contrast to rider position measurements (e.g. via stereo camera) it benefits from the independence of e.g. markers that need to be tracked or models that describe the mass distribution of a rider. Also, as measured torques are proportional to accelerations, no time consuming differentiation is needed, as it would be for optical position measurements. However, these benefits come at a cost, as the following section describes.

3.1.1 *Rider induced roll torque determination*

The motorcycle mockup is fixed on the hexapod via an additional roll axis. However, the rotational degree of freedom is directly supported against a load cell as shown in the right picture of figure 3. This setup has been chosen to 1) bring the roll axis as close as possible to the system CoG and 2) prevent the load cell from carrying static loads, which would unnecessarily increase the needed measuring range and therefore decrease the measurement resolution.

Even without a rider moving on top of the mockup, there will be a torque acting around the roll axis due to inertial properties of the simulator. To calculate this torque, the rider is assumed a rigid point mass in a fixed position with respect to the mockup. With m and J_{xx} being the total mass and inertia of mockup and rider and y, z_{CG} being the total CoG's location with respect to the roll axis and $y, z, \varphi_{\mathrm{HEX}}$ being the planar motions of the hexapod, the torque in zero-configuration (i.e. non-moving rider) $T_{\mathrm{LC},0}$ around the roll axis results can be calculated by multiplying the motion vector $\boldsymbol{x}$ (equation 2) by the body parameter vector $\boldsymbol{\beta}$ (equation 3).

$$T_{\mathrm{LC},0} = \boldsymbol{x}\boldsymbol{\beta} \tag{1}$$

with the motion vector

$$\boldsymbol{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}^T = \begin{bmatrix} \ddot{\varphi}_{\mathrm{HEX}} \\ \cos(\varphi_{\mathrm{HEX}})\ddot{z}_{\mathrm{HEX}} + h_r\dot{\varphi}_{\mathrm{HEX}}^2 - \sin(\varphi_{\mathrm{HEX}})\ddot{y}_{\mathrm{HEX}} - g\cos(\varphi_{\mathrm{HEX}}) \\ g\sin(\varphi_{\mathrm{HEX}}) - \cos(\varphi_{\mathrm{HEX}})\,\ddot{y}_{\mathrm{HEX}} - \sin(\varphi_{\mathrm{HEX}})\ddot{z}_{\mathrm{HEX}} \end{bmatrix}^T \tag{2}$$

and the body parameter vector

$$\boldsymbol{\beta} = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \end{bmatrix} = \begin{bmatrix} J_{xx} + my_{CG}^2 + mz_{CG}^2 + h_{ax}mz_{CG} \\ my_{CG} \\ mz_{CG} + mh_{ax} \end{bmatrix} \tag{3}$$

During online simulation, this modelled torque in zero-configuration (i.e. non-moving rider) is subtracted from the measured torque and this difference is then used as input to the vehicle dynamics model by applying an external torque around the longitudinal axis of the virtual motorcycle's CoG.

$$T_{\mathrm{ext,x}} = T_{\mathrm{LC,meas}} - T_{\mathrm{LC},0} \tag{4}$$

This torque difference includes any torques that result from deviation of the rider of his zero-configuration, e.g. change of body posture as well as shaking the hips, legs or arms.

The parametrization of $\boldsymbol{\beta}$ happens through a specific identification maneuver, where the hexapod is excited along the lateral and vertical axis and around the lateral axis with sine sweep signals.

3.2 Measurement Motorcycle with Roll Torque Excitation

For on road testing, a Honda NC 700 X is used, that is equipped with a multitude of sensors including steering angle and torque, suspension travel, wheel and engine speed as well as a 6 axis inertial measurement unit (IMU) with integrated Kalman filter and GPS referencing. Additionally, to the steering entities, the other rider inputs (throttle, clutch, gear and brake pressures) are recorded as well. All data is recorded via a National Instruments™ based DAQ system with 100 Hz sampling rate. Except for the sensors, all measurement equipment (DC/DC-converter, PC, NI-DAQ) is integrated in the helmet case so that no additional luggage cases are needed.

Figure 5. Measurement Motorcycle with Equipment Integrated in Helmet Case, Roll Torque Excitation Module

In order to generate roll excitations (preferably a roll torque step function), a support structure made of aluminium profiles is fixed on the motorcycle's luggage rack (see figure 5, right). At the start of each experiment, two weights are mounted on each side of the structure. The supervisor of the experiment may choose to fix one weight with a release-system. We use a radio signal to trigger that system, so that the rider doesn't know about the timing of the excitation. At the push of a button on a remote control, one of the weights falls to the ground, while the other is still mounted. This generates a roll torque jump with an amplitude around 50 Nm.

3.3 Camera Position Tracking

The measurement motorcycle does not allow for a torque measurement as used on the simulator. Some approaches have been made in literature to measure coupling torques and forces between rider and motorcycle in real road riding. However, a holistic measurement of all contact points and all directions is neither affordable nor feasible at the time. For the sake of this study, a camera based measurement system was implemented that uses a mono camera (59,94 fps, 1280x720p resolution) fixed on the luggage rack of the motorcycle or simulator respectively. The rider wears a back protector with marker points fixed at specific locations. The pixel positions of the markers in each frame are used to calculate the rider's position in the sagittal plane relative to the motorcycle. For stationary reference testing, a measurement error of less than 1 mm could be achieved. For synchronization purposes, a LED is mounted close to the camera lens, which is controlled by the NI DAQ System, so that the on/off state is recorded in synchronization with all other measurements. We use a blinking pattern similar to a pseudo binary noise signal. This blinking pattern can easily be extracted from the video material. In post processing, the LED Voltage U_{LED} and the blinking states observed by the camera L_{CAM} are resampled. Cross correlation of the two signals allows to find the exact delay between DAQ and camera data. The output data is sampled at 20 Hz, as no signal above 10 Hz is expected.

The method is depicted in figure 6. It shows the tracked points on the rider's back for both real- and simulator tests, as well as the synchronization method.

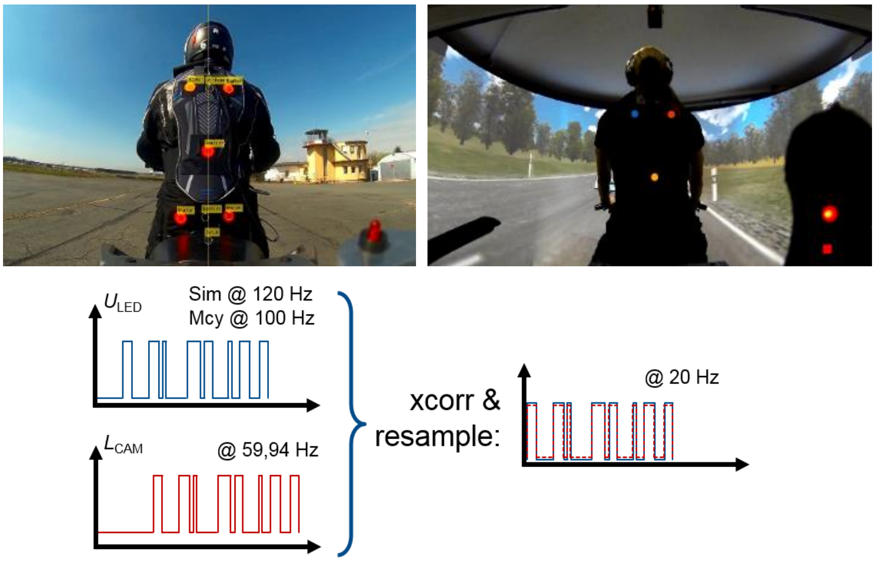

Figure 6. Camera Based Position Tracking and Data Synchronization

4 EXPERIMENTS

According to the methods presented in chapter 2 and relating to the nomenclature in figure 2, the following experiments have been performed, where all excitations were implemented with step function values:

a. For getting to know the coupling between steering excitations and rolling motion of the upper rider body as well as the other way round, synthetic excitation investigations were performed on the simulator. The rider had to sit on the mockup and grab the handlebar as he would do during a normal motorcycle ride. The rider's body was excited by a step function movement either of the whole simulator around the roll axis or only of the handlebar around the steer axis. The controlled parameter was in both cases the relating steer- or roll angle. To ensure comparability and avoid learning effects, the excitations were arranged in a random manner. Furthermore, the excitations around steer and roll axis were mixed. Of particular interest was the observability of that body excitation in the respective other sensor.

b. To compare the rider's reaction between active riding and passive sitting during the excitations, there were investigations carried out while a simulated country road ride with slight, long corners as well as on a straight road. The driving speed was 80 km/h, i.e. within stable dynamic conditions. Excitations were performed to both sides during cornering as well as while straight riding. Therefore, the rider's body is assumed to have different body tension, as the rider must partially support his weight on the simulator while being subject to roll angles. The start point of the excitation was chosen randomly by the operator by adding an additional roll torque of maximum 170 Nm to the corresponding input.

c. Finally, the real riding investigations were performed. As explained above, only roll excitations have been applied, but no steering excitations. Therefore, bags filled with sand were mounted on both sides of the motorcycle with a lever arm of half a meter. After releasing one of the bags, the remaining bag pulls down with its weight and by this an additional roll-torque on the motorcycle was applied. The added torque was regulated by the weight of the sand bags. An additional torque of 50 Nm was the maximum possible excitation due to structural stability of the mechanical system. The positioning as well as the choice of using bags instead of rigid weights were made for safety reasons, i.e. to prevent collisions of the falling weight with the rider or motorcycle and guarantee instant speed reduction of the fallen weight.

5 PERFORMING THE EXPERIMENTS

On the simulator, four different riders performed the described experiments, while for the real world investigations only two of them participated the study. All the experiments were repeated twice. In the following the sources of errors and unknown influences are listed:

- Evident oscillations between 7 and 8 Hz in the load force measuring data, especially without rider, cannot completely be explained with known elasticities of the mockup rear frame. A connection between the acceleration of the hydraulic actuator and these oscillations was found.

- Because of bearing frictions around the roll-axes of the simulator, remaining torques up to 10 Nm around the zero position cannot clearly be assigned to human body leaning influences.

- During real world testing a falsification of the used testing method for roll torque step function excitations was achieved. The used method was conceptual evaluated against other excitation methods, like using of repulsion, or moving masses. After some modifications, regarding to improvements of the mechanical stiffness of the test apparatus the investigation should give new knowledge on the rider-motorcycle coupling.

6 EVALUATION OF EXPERIMENTS

In the following the generated results are shown. Unless stated otherwise, the riders body movements are represented by the lateral movement of the midpoint between the two shoulder blades, relatively to the mockup fixed coordinate system. The shown plots are an exemplary representation of one picked out rider for all different test persons, where similar behaviour was observed.

6.1 Synthetic Steer to Roll Transfer

As already described, the first part of the investigation consists of synthetic steer excitations on a passive sitting rider on top of the mockup. In the upper plot of figure 7 the transmission of the sudden handlebar acceleration $\ddot{\delta}_{\mathrm{mock}}$ into the acceleration of the upper rider body $\ddot{y}_{\mathrm{rid}}$ is shown. The handlebar movement starts at the time of $t = 1$ s. A clear and quite direct following of the upper body movement with only a short time delay is visible. Thus, a stiff coupling of steering movements and the movement of the rider's body can be interpreted. There also is no visible oscillation of the rider's body after the end of handlebar movement. Rather in the lower plot of figure 7 a damping by the human body is visible. The red solid line represents the measured roll torque during a steer excitation with rider. There is a further time lag between the lateral acceleration of the rider's upper body and the torque measured around the roll axis T_{φ}. This comes from the sluggish movement of the rider's shoulders, which is not represented well in the calculated mean value of the upper body movement in this work. The dotted, red line represents the measured roll torques after steering excitation, but without a rider sitting on the mockup. Here, an oscillation can be seen, that comes from structural elasticity but is completely damped by the rider mass or even the detuning of the eigenfrequency.

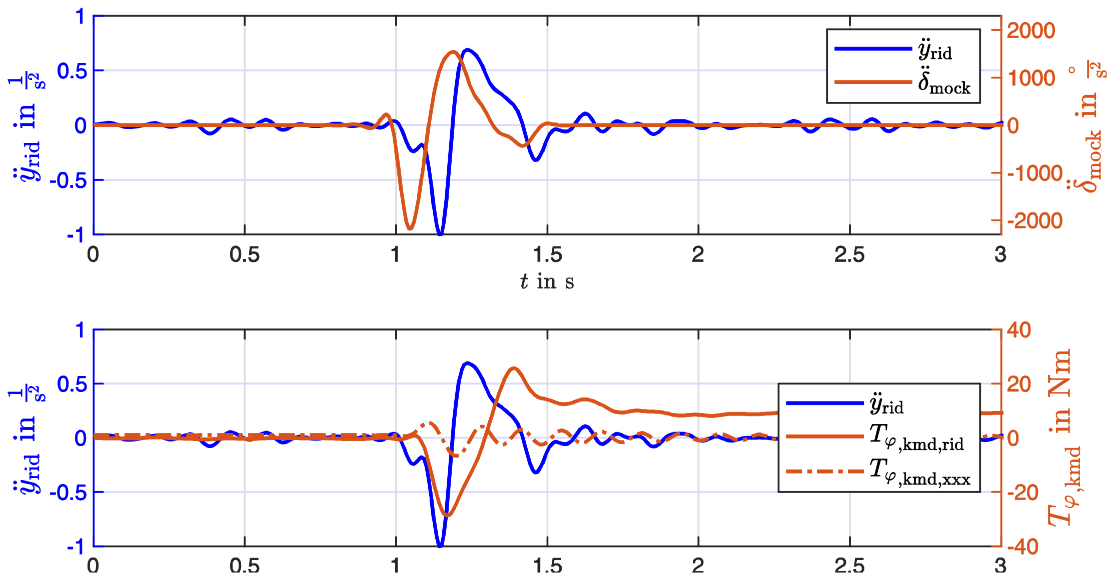

Figure 7. Coupling steer angle step function to riders upper body movements and roll torque

In summary the transfer from steering excitation to measurable roll torque can be modelled by a proportional element with delay- or dead-time.

6.2 Synthetic Roll to Steer Transfer

The counterpart to the synthetic steer excitations were the investigations with roll angle step functions. Meanwhile the steer angle was controlled to zero, what made a measurement of the coupled torque through the rider's body and arms into the handlebar possible, by looking at the needed torque of the steer actor.

In the upper part of figure 8 the roll acceleration of the hydraulic hexapod $\ddot{\varphi}_{\text{hex}}$ is plotted in orange whereas the resulting acceleration of the human upper body $\ddot{y}_{\text{rid}}$ is shown by the blue line. The excitation signal shows oscillations due to imperfect control of the hexapod. Interesting is the first peak of both accelerations. They are of different sign, as can be explained by the great inertia of the human body around the roll axis. After some more oscillations, coming from the regulating of the hydraulic actuator, the human body is in phase oscillating with the excitation movement of the hydraulic actuator. This roll-to-upper-body coupling makes a system identification more difficult, than with the steer-to-body coupling. Thus, there has to be a non-minimum-phase system behaviour with at least more than one zero in the right half-plane of the pole-zero model. Furthermore, the system is vibratory, what results in at least more than two poles. In the lowest plot of figure 8 the difference in roll Torque T_{φ} between the roll excitation with and without rider is shown. The first contrary motion of the upper body to the rolling simulator cannot be seen in the measurement of the load cell. Here the first very fast movement of the hydraulic actuator is dominating comparing the influence of the human body movement. From here the influence of the moving rider body can be seen in the values of the load cell, again with a damping effect compared to the values without rider. The actual coupling between roll excitation and steer motion or torque through the rider's body, arms and hands on the handlebar is showed in the middle plot of figure 6. The coupling force or rather torque is illustrated with the orange line. The influence through the coupling of the rider is visible, but in a negligible range, if you take into account a minimum of 4 Nm to overcome the breakaway torque of the actual steering actuator, that is subject to revisions at the time of printing this document.

In summary the roll-steer coupling has less influence than the other way round. As well the modelling of the human body behaviour on the basis of roll excitations is way more difficult, than around the steer axis.

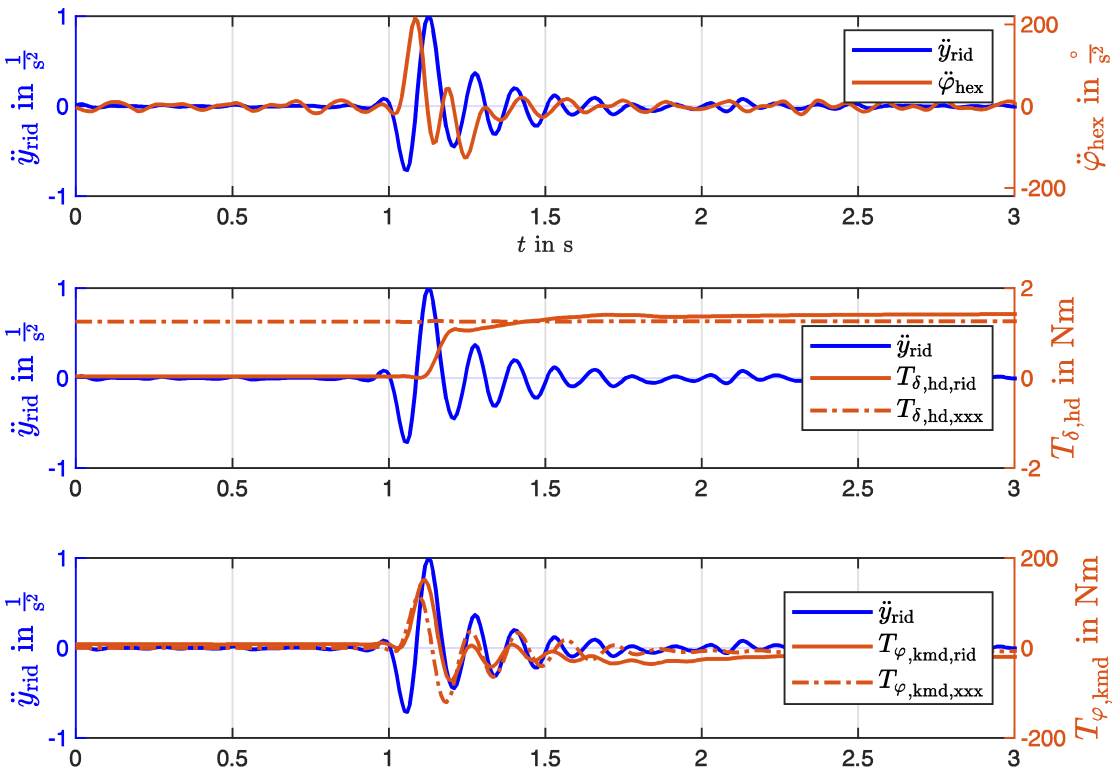

Figure 8. Coupling roll angle step function to rider's upper body movements and steer torque

6.3 Online Simulation Roll Disturbance

The so far discussed investigations are useful for determine the coupling behaviour of certain excitations to the movement of the rider's body. To understand better the difference of this behaviour whilst a closed loop simulator ride, some further investigations were performed. To have a comparable control value between real world tests and the simulator and for stability reasons, an additional roll torque instead of an angle was applied. This roll torque now not only results in direct roll motion but furthermore in a steer motion because of the coupling between steering and rolling through the driving dynamics model. This leads to a lot more excitation around the steer axis than around the roll axis because of the less inertia of the steering system compared to the rest of the moving system.

As shown in figure 9 in the upper right plot, this leads to an excitation of the rider's body oscillation in its eigenfrequency around the roll axis with about 2-3 Hz. It is not complete clear, where this excitation comes from, because there seems to be no real correlation between the acceleration of the hydraulic actuator roll movement and the human body. The most correlation effects can be seen between the derivate of the steer actuator torque and the riders body acceleration. There also is a correlation between both the derivate of the steer torque and the measured roll torque derivate, what leads again to the idea of a strong coupling between steer excitations and human body movements. The orange lines, where BRT stands for the used driving dynamics software Bike Real Time, illustrate the bad subsequent behaviour of both the actuators to the input of the software. An idea of the whole cycle is a first excitation of the rider's upper body by the non-homogenous steering actuator movements. These coupling effects are measured in the load cell, what creates a new input signal into the simulating model, where the rider is modelled as a stiff mass. This leads to an unstable simulator behaviour.

After these investigations, the movement of the hydraulic actuator during the country road closed loop simulator ride was re-enacted with the same rider, but without any visual feedback in open loop mode. This led to twice the amplitude of the rider's body oscillations between 0.5 and 4 Hz, because of the loose muscle contraction and the missing predictability of the situations by the rider. For further rider model investigations this hast to be taken into account. Performing some synthetic tests for figuring out the rider's parameters might not represent the active riding values.

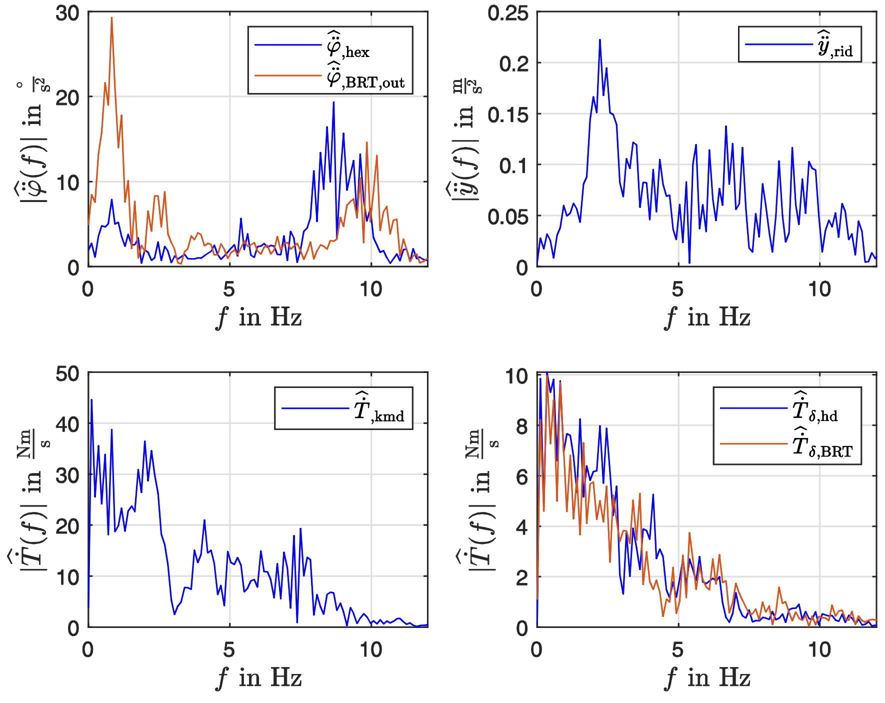

Figure 9. Roll torque step function on Closed loop country road ride

6.4 Real-Life Roll Disturbance

To get a comparison and verifying of the results on the dynamic riding simulator some real motorcycle riding experiments were performed. Especially the strong coupling effects between roll- and steer torque were of interest. Because of some mechanical stiffness problems, the mounting for the sand bags and even the sand bags itself lead to a strong oscillating roll torque excitations. These excitations were of significantly higher amplitudes than the excitations by the releasing of one sand bag and resulting roll torque to one side. The oscillating sand bags furthermore induced twisting motion of the rear frame and luggage rack, where the camera for tracking the rider's motions was mounted. To sum up, the results are not usable for a scientifically statement yet. The module is subject to revisions mainly by adding a frame to increase stiffness and preventing the swinging motion of the sandbags whilst being fixed on the motorcycle.

The subjective experience gained by one author of this paper is a strong noticeable coupling between rolling torque excitations and the steering torque, that needed to be applied by the rider for driving straight ahead.

7 DISCUSSION & OUTLOOK

The Measurements show a clear connection between roll and steer through rider coupling. The coupling between steer excitations and upper human body movement is completely different to the coupling from rolling to human body movement. Steer excitations are passed into the upper body with only a time lag but without any other changes. This also can be measured in the load cell, which means there is a strong steer-roll coupling. The other way round, with roll excitations the rider's upper body shows a complete different behaviour. Because of the great inertia the movements are in the opposite direction than the excitation. After some oscillations the body is again in phase with the roll excitation and has a damping effect.

This leads to the idea of using a resonating system for modelling the human rider on a dynamic riding simulator. Because of the non-phase minimal system behaviour, a state space model is recommended. Therefore, the different behaviour of an active riding to passive sitting rider has to be taken into account during the examination of the human's parameter. This leads to different stiffness and damping parameters, depending on the muscle contraction of the rider's body.

The real motorcycle's torque excitation was not mechanically proof and experiments must be repeated. Even there a strong coupling between roll and steer torque was noticeable.

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