Steering Torque Measurement on Motorcycles

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Abstract

The essential control variable for riders to influence the lateral dynamics of a motorbike is the steering torque. In contrast to passenger cars, it is so far not common to measure this quantity. However, for scientific investigations that deal with the derivation of handling measures, steering torque has to be known. In single studies, different approaches to measure the steering torque are realized.

The target of the presented work is to realize a robust steering torque measurement setup for bike dynamics investigations. This setup should influence the geometry of the steering system and the driving behavior of the motorbike as little as possible. It also should be easily mountable and removable without repeated calibration.

Because a motorcycle has no steering column as in a car, the steering torque cannot be measured directly in an easy manner. Motorcyclists generate the steering torque by applying different forces to the right and left handlebar grips. These handlebar forces generate reaction forces in the connection blocks of the handlebar with the upper triple tree clamp. The measurement setup is realized in a way that these reaction forces are measured. For this purpose two force measuring bolts from a former weight sensing system for advanced passenger safety are mounted with adapter plates between the handlebar and the upper triple tree clamp. The handlebar thereby increases by 8 mm with otherwise unchanged components and steering geometry. The used force measuring bolts have a uniaxial sensitivity and measure to a good approximation only the force perpendicular to the steering axle. Given the defined mounting position, the steering torque can be directly evaluated. The described setup is calibrated on a test bench. First rides on the test bike show that the measurement setup fulfils the requirements. Further test rides will be carried out to analyze the measured steering torque in dynamic riding situations.

1 Introduction

To control the lateral bike dynamics, the rider applies different left and right handlebar forces which produce a steering torque. This steering torque T is the input variable, which manipulates the lateral bike states, like lateral acceleration a_y, yaw rate $\dot{\Psi}$ and roll angle λ as illustrated in Figure 1.

Figure 1: Input variable steering torque for lateral bike dynamics

From a system dynamics point of view in contrast to passenger cars, the steering system of a motorcycle cannot be separated and the steering angle δ has to be seen as bike state. Despite the much more complex transfer behavior of motorcycles they are not equipped with steering torque and steering angle sensors like cars.

But when studying the handling of bikes knowledge of the steering torque is required. Kooijman and Schwab [1] give a detailed overview of handling aspects for motorcycles. All listed indices to rate handling describe in some way the relation between steering torque and a lateral bike state. For example, good handling is achieved in steady turning when the roll factor T/λ has a low value with small negative steering torque [2]. When the time lag between the steering torque T and the yaw rate $\dot{\Psi}$ is small the bike has good handling for avoiding an obstacle [2]. Further examples of handling indices can be found in [1].

Since a motorcycle has no steering column like a car, the steering torque cannot be measured directly in an easy manner. In literature only single studies measuring the steering torque can be found, which use different measurement approaches. In [3, 4] special torque sensing assemblies integrating torque measurement shafts have been constructed. Also Figure 2 shows such a realization of direct torque measuring by a measurement shaft.

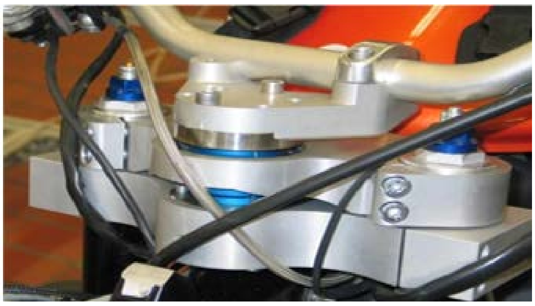

Figure 2: Steering torque measurement with torque measurement shaft

With the advantage of direct measuring of the steering torque there come the disadvantages of a complex construction and a changed steering feeling. Another approach is to measure the steering torque indirectly. For example [5] applies bi axial load arms at the handlebar grips and calculates the steering torque with the measured handlebar grip forces. In [6] a special realization is described where a custom build transducer with strain gauges on a cantilever is constructed for steering torque measurement. More common is pasting strain gauges directly onto the handlebar and to calculate forces and the steering torque from the measured deformations. This approach, for example used in [7,8], does not require any bike modifications. The application of strain gauges needs corresponding expertise and an extensive calibration of quite sensitive measuring elements.

Since no general steering torque measurement setup for bike dynamic investigations is available, the goal of this work is to put forward a robust measurement setup for a test bike to handle easily. This setup should influence the geometry of the steering system and the driving behavior of the motorbike as little as possible. It also should be easily mountable and removable without repeated calibration.

2 Measurement concept and realization

2. 1 Concept

To steer a bike, motorcyclists apply different handlebar forces F_{HB} at the right and left handlebar grips. These forces generate reaction forces in the connection blocks between the handlebar and the upper triple tree clamp. With the part F_S of the reaction forces acting perpendicular to the steering axis at the well-defined distance l_i from the connection blocks to the rotation point, the steering torque T can be evaluated. The torque equilibrium at the handlebar yields:

$$T = \left(F_{HB,R} - F_{HB,L}\right) * l_a = \left(F_{s,L} - F_{s,R}\right) * l_i$$

Figure 3 depicts a simplified handlebar model introducing the used notation.

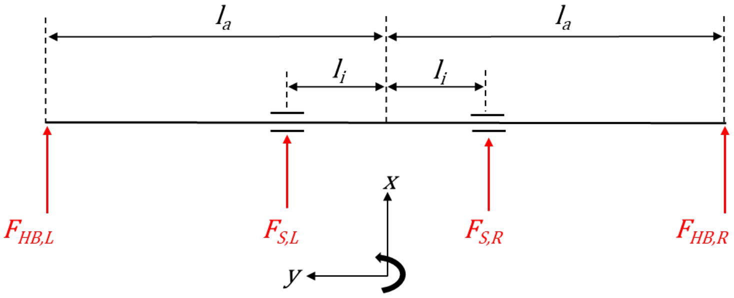

Figure 3: Simplified handlebar model. T steering torque, F_{HB} rider force at handlebar grip in longitudinal direction, F_S reaction force in connection block

An advantage of this indirect way to measure the steering torque is that beside the steering torque the handlebar grip forces acting in longitudinal direction can be approximated.

$$F_{HB,L} = -\frac{1}{2} * \left[F_{S,L} * \left(1 + \frac{l_i}{l_a}\right) + F_{S,R} * \left(1 - \frac{l_i}{l_a}\right)\right]$$

$$F_{HB,R} = -\frac{1}{2} * \left[F_{S,L} * \left(1 - \frac{l_i}{l_a}\right) + F_{S,R} * \left(1 + \frac{l_i}{l_a}\right)\right]$$

2.2 Sensor principle

The described concept needs a force sensor with uniaxial sensor sensitivity to only measure the reaction force perpendicular to the rotation axis of the steering system. For this purpose a force measuring bolt from a former weight sensing system, originally developed for passenger classification in cars [9] but no longer produced, has been chosen. This force sensor has a uniaxial measuring direction as displayed in Figure 4.

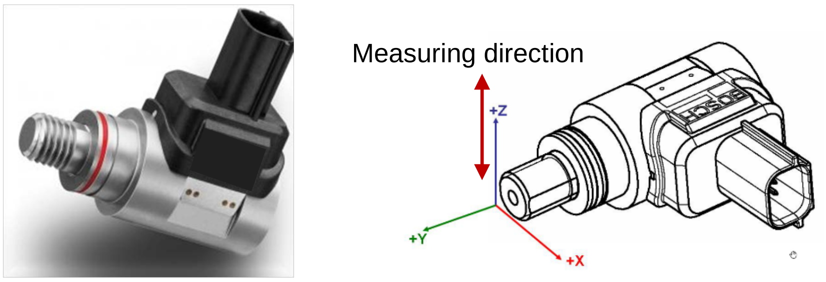

Figure 4: Force measuring bolt with its measuring direction

The working principle of the force sensor, as illustrated in Figure 5, is based on measuring the deflection of a bending beam caused by the applied force F. This deflection is monitored by measuring the change of a static magnetic field with a Hall-sensor. The sensor provides analog output data (voltage value), which is linear to the applied force.

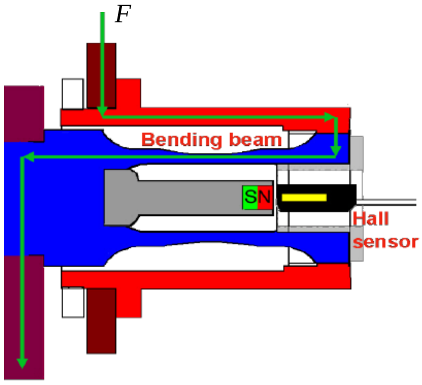

Figure 5: Scheme of the used force sensor

Additionally the force sensor features a mechanical limitation of the maximum strain on the bending beam. The mechanical design of the force sensor is developed to ensure a minimum sensitivity against forces and moments lateral to the main measuring direction.

2.3 Construction

A model of the finally assembled steering torque measurement setup is displayed in Figure 6.

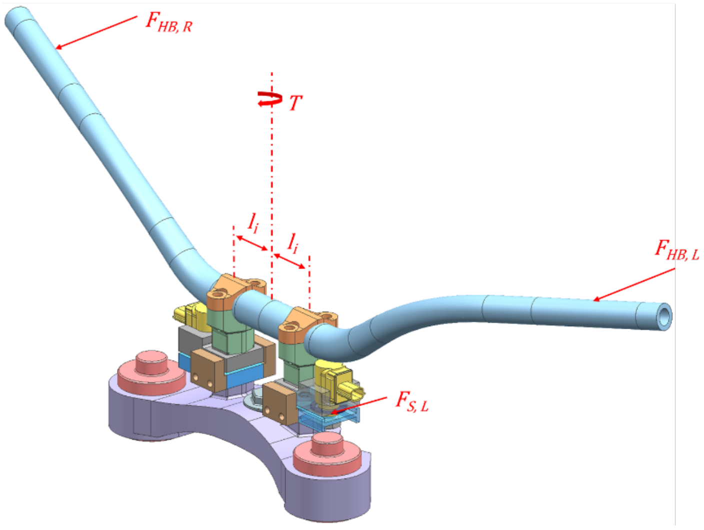

Figure 6: Model of the measurement setup integrating two force measuring bolts
force sensor (yellow), adapter plate I (grey), adapter plate II (blue), overload protection (brown)

The two force measuring bolts (yellow) are integrated with opposite mounting directions between the handlebar connection blocks (green) and the upper triple tree clamp (purple). For this purpose two adapter plates (grey and blue) respectively have been constructed. They are attached to the connection blocks or the triple tree clamp using the existing screw fittings. The two adapter plates themselves are connected by the measuring bolt of the force sensor. In addition to the overload protection of the force sensor, the construction includes overload stops (brown).

Figure 7 shows the final realization of the steering torque measurement setup. This setup does not require any changes of components of the steering system. Only the height of the handlebar is increased by 8mm. The modular design allows for easy mounting and dismounting.

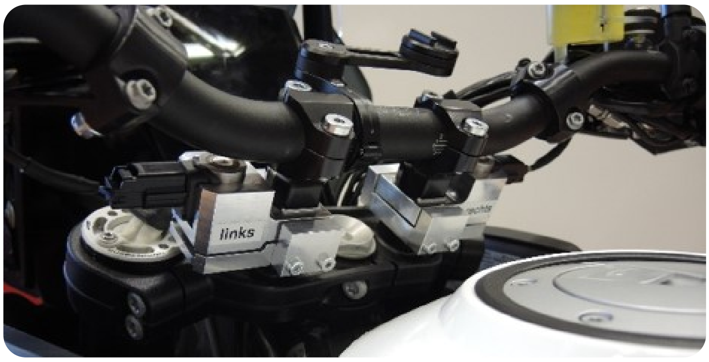

Figure 7: Steering torque measurement setup

4 Calibration

For calibration measurements under constant and repeatable conditions, a test bench has been built up. A design drawing is shown in Figure 8.

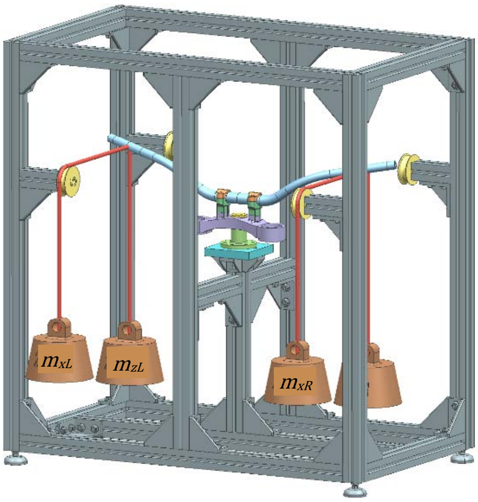

Figure 8: Test bench for calibration. Weights at pulleys in the front → pulling force (negative), weights at pulleys in the back → pushing forces (positive)

The upper triple tree clamp is stiffly fixed with the test bench. By hanging weights in the x-direction, pulling or pushing forces can be applied, which produces a steering torque dependent on their difference. The weights m_x in Figure 8 produce pulling forces. For pushing forces, the pulleys in the back have to be used. With these forces at their exactly defined positions, a reference value T_{ref} for the steering torque to measure T_{meas} is evaluated.

$$T_{ref} = \left(F_{HB,R} - F_{HB,L}\right) * l_a \qquad T_{meas} = \left(F_{S,L} - F_{S,R}\right) * l_i$$

By hanging weights in the z-direction, the influence of the rider's supporting force in normal direction is taken into account. These forces are parasitic forces concerning steering torque measurement.

To consider all load cases, different weights are applied as pulling and pushing forces at the left and right of the handlebar. This results in a matrix of measured steering torques as illustrated in Figure 9. The diagonal from top left to bottom right corresponds to the straight ride with zero steering torque. The green marked fields, where one of both weights is zero, correspond to the one-handed ride.

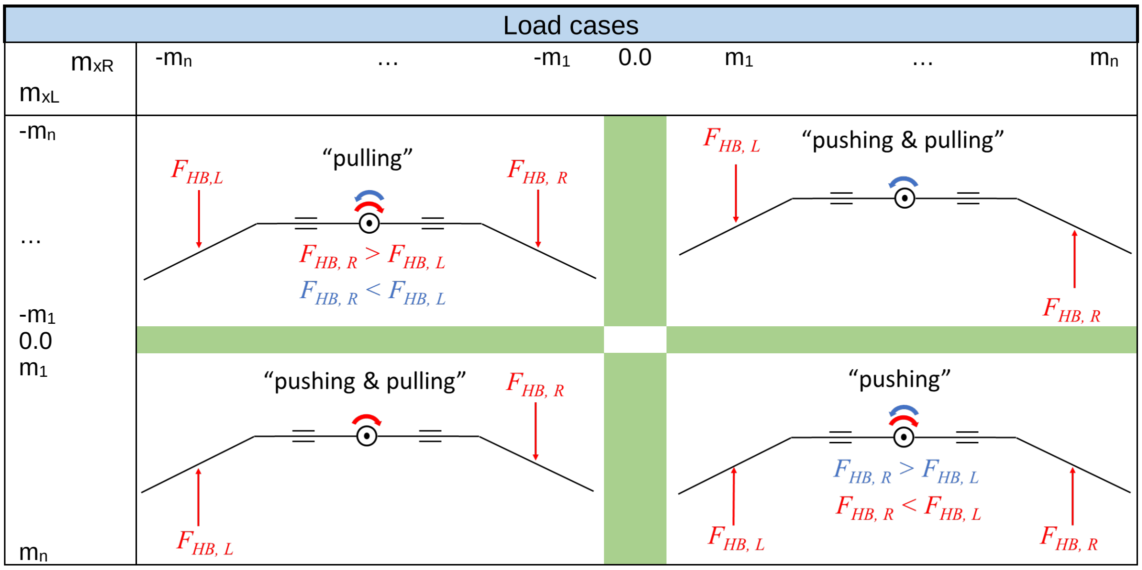

Figure 9: Load cases for calibration by applying different left/right weights ("negative" weights correspond to pulling)

Figure 10 shows the results of the calibration measurements plotting the value pairs (T_{ref}, T_{meas}). Theoretically these points lie on a line through the origin with a gradient of one. Of course there are disturbing effects like mounting inaccuracies (e.g. small error in sensor direction), sensor hysteresis or parasitic loads which lead to measurement errors. By means of a correction factor, which is determined with help of the regression line, the influence of systematic errors is reduced. This static calibration results in a mean absolute measurement accuracy of ±1,24 Nm of the developed measurement setup.

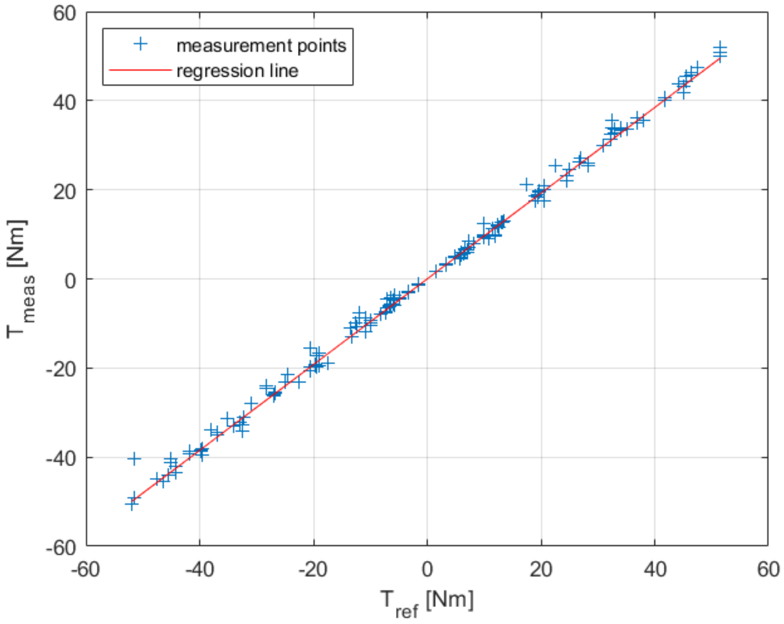

Figure 10: Scatter plot of measured points (T_{ref}, T_{meas}) and linear regression line

Although the used force sensor is able to measure positive and negative forces in its sensitive measuring direction, it has been designed for passenger classification in cars, where only positive or negative forces occur dependent on mounting. In the sensor design no focus was put on change of force direction (positive to negative and vice versa). For small forces with changing sign, the used force measuring bolt probably is not the optimal sensor.

5 Measurements

The steering torque measurement setup is built to perform deeper bike dynamics investigations especially concerning the input/output transfer behavior. Primary test rides to check the functionality of the measurement setup have been carried out. Different riding maneuvers, smooth ones and also extreme ones, yield no change in steering feeling. Thus the construction does not introduce significant elasticity in the steering system.

An example measurement of curve braking with Motorcycle Stability Control [10] is displayed in Figure 11.

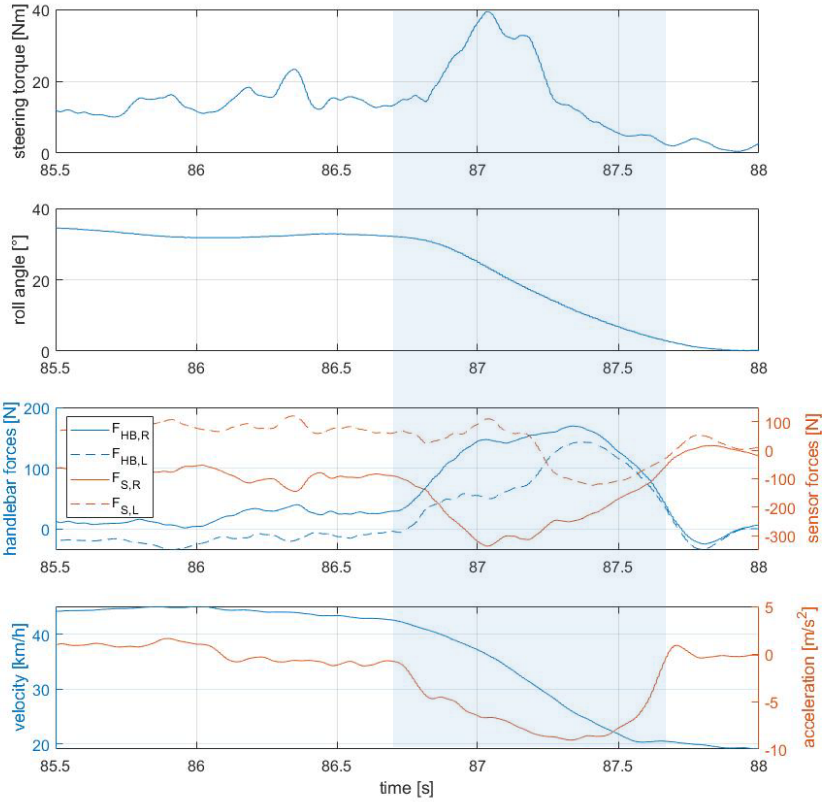

Figure 11: Example measurement of curve braking. Steady cornering at beginning, braking in blue area

The maneuver begins with steady cornering (right turning) at a velocity of 45 km/h (blue line, 4. diagram) and a roll angle around 35° (2. diagram). To steer the bike on the circular ride the rider applies a steering torque around 15 Nm contrary to the curve direction (1. diagram). The rider creates the steering torque by slightly pulling at the outer and pushing at the inner handlebar grip, which can be seen in the handlebar forces (blue lines, 3. diagram). At 86.7s the rider initiates ABS braking down to a deceleration of approximately 9 m/s^2 (4. diagram, orange). Motorcycle Stability Control limits the deceleration gradient to keep the bike stable. To stay on the circular ride the rider counteracts the brake steer torque by applying a steering torque up to 40 Nm contrary to the curve direction. Looking at the handlebar forces in the time span of braking (blue area) one can see that the rider first pushes at the at inner handlebar grip to compensate the brake steer torque. Delayed also a pushing force is measured at the outer handlebar grip since the rider has to support the upper body during deceleration.
The measurement setup has been checked with more maneuvers like slalom, evasion, straight braking and steady cornering. All analyzed measurements are plausible and give a good insight how the rider steers the bike. The measurement setup is now available for further bike dynamics studies.

6 Summary and outlook

In the paper a robust setup for steering torque measurement is presented, taking advantage of the defined force transmission at the connections between the handlebar and the triple tree clamp, which is a good position to place force sensors. Requirements with no modification of bike components, no change in steering feeling and a construction easy to mount and remove are fulfilled by this setup. The steering torque is measured with a sufficient accuracy for the extensive vehicle dynamics studies planned next. With the steering torque the handling and the transfer behavior can be evaluated. The steering torque gives insights into how a rider steers a bike and can also be used to validate and improve simulation studies. Furthermore, the steering torque may be used to enhance existing motorcycle safety and assistance functions or to support new functions.

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Keywords

motorcycle safety, steering torque, force measurement bolt, bike dynamics