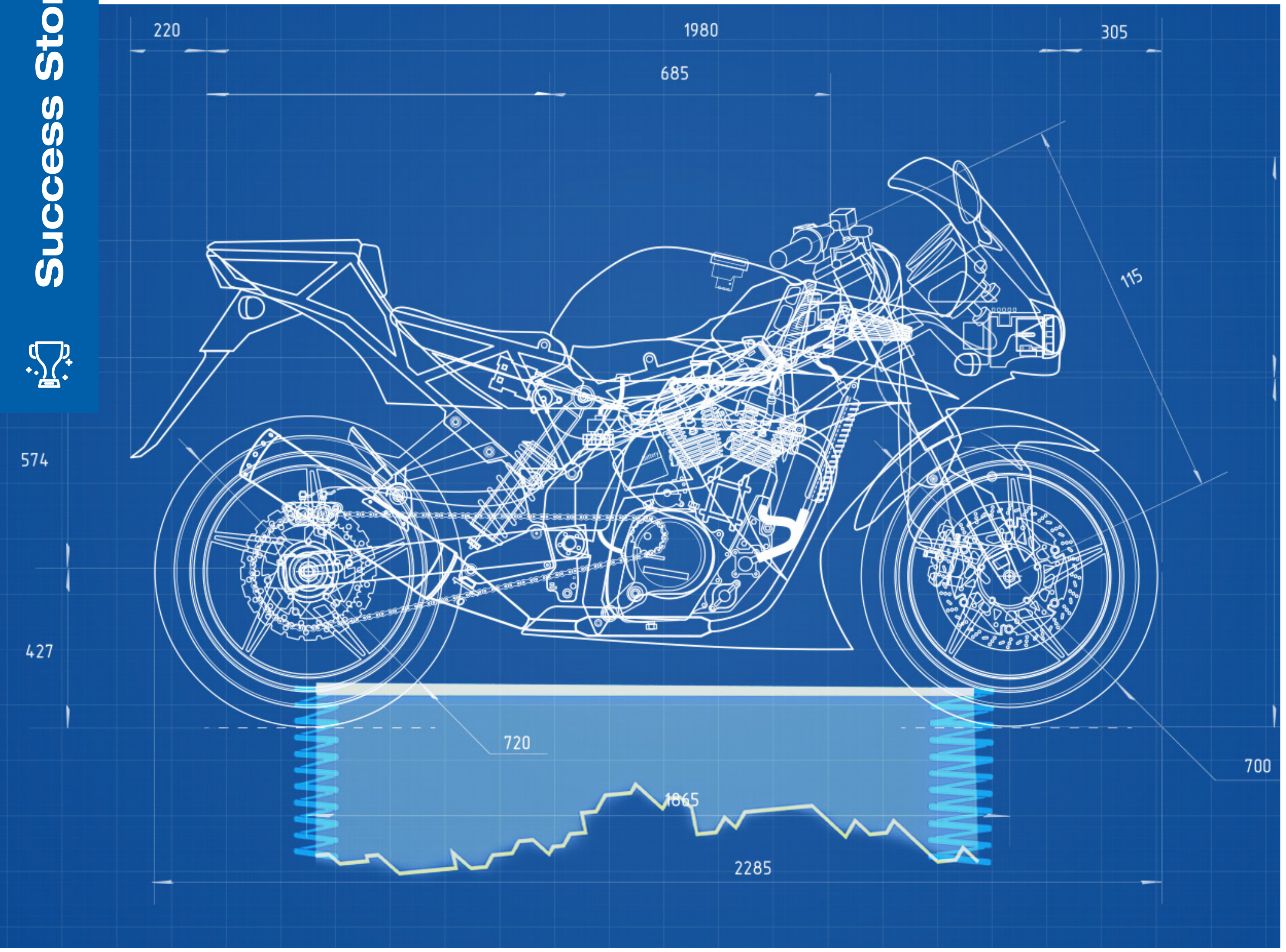


More Stability with MotorcycleMaker

The experts from the Italian engineering firm Soluzioni Ingegneria have investigated the conditions under which critical instabilities occur when riding a motorcycle and how they can be avoided. Their research has resulted in control technology for a semi-active damper system. Its effectiveness has been validated in virtual test driving with MotorcycleMaker.

Motorcycle riding is a way of life. But the freedom on two wheels entails risks. Unlike cars, bikes have no crumple zones and even small mistakes on the handlebars can quickly result in horrific consequences. That is why riding stability is an important development topic with motorcycles. It depends on many factors such as the size of the tires and wheels, vehicle speed and, last but not least, the suspension design.

Basically, the suspension should be engineered in a way that ensures the motorcycle's stability in any riding condition: on a straight-line path, in cornering, while accelerating and while braking. However, a relatively new class of motorcycles – crossover bikes – confronts suspension developers with special challenges. This type of motorcycle is becoming increasingly popular and, as the name suggests, is suitable for a wide range of uses: anything is supposed to be possible, from easy to difficult off-roading through to highly sporty riding on backroads. To deliver this type of performance, crossover bikes require high engine output as well as very good handling characteristics. In addition, riders expect high levels of comfort and would like to fully load their vehicles with gear for longer tours. Combining all these requirements in a single motorcycle category seems to be contradictory and calls for new approaches in suspension development.

The integration of new advanced driver assistance systems (ADAS) is such an approach. While braking and traction control systems already found their way into motorcycles several years ago, semi-active suspensions are now increasingly being brought to market. The controlled dampers of the smart suspensions promise to yield further improvements in riding stability.

In a research project, the specialists from Soluzioni Ingegneria, an Italian engineering services provider, investigated how the stability of crossover bikes can be enhanced by semi-active damper systems. Their investigations were focused on weave and wobble. These instabilities frequently lead to falls and can affect seasoned motorcycle riders just as well as inexperienced riders. Consequently, they are less dependent on the rider's skills, but closely linked to the characteristics of the vehicle itself.

Instabilities of Motorcycles

Weaving describes a complex form of oscillation in which the front end of the vehicle and the vehicle's rear execute a coupled oscillation also around the steering axle. In this process, the entire vehicle performs a swerving motion around the vertical axis which is superimposed by an additional tilting motion around the longitudinal axis. Weaving only occurs at higher speeds above 100 km/h, with growing intensity as speed increases. The weave oscillation is excited for instance by steering movements that cause a yaw movement. They may be introduced by the road as well as by aerodynamic forces emanating, for example, from pieces of baggage. If the weaving movements escalate, even well-practiced riders can no longer control them and will fall.

Overview

Customer

Soluzioni Ingegneria

Country

Italy

Products

- MotorcycleMaker
- MotorcycleMaker/HIL

Challenge

Development and validation of a controller for semi-active damping to enhance the riding stability of crossover motorcycles.

Solution

- Sensitivity studies based on an MKS model
- Development of a controller and integration of the Simulink model in MotorcycleMaker
- Virtual test driving in critical ranges of vehicle dynamics
- Further steps: HIL tests with real-world steering damper

Figure 1: Development of a weaving movement at high speeds

Wobble is a parametrically excited oscillation of the steering system around the steering axle in which just a few, very high steering angle amplitudes occur in rapid succession. The forces may be of a magnitude which the driver can no longer control. There are various factors that influence wobble. Aside from bumps in the road, tire characteristics and tire inflation pressure, etc., the enormous stiffness of today's suspensions is one of the major causes of wobble occurring with modern motorcycles. Additional factors are good tracking and grip which enable higher cornering speeds even on bumpy ground and make it possible in the first place for riders to push into critical speed ranges on respective roads.

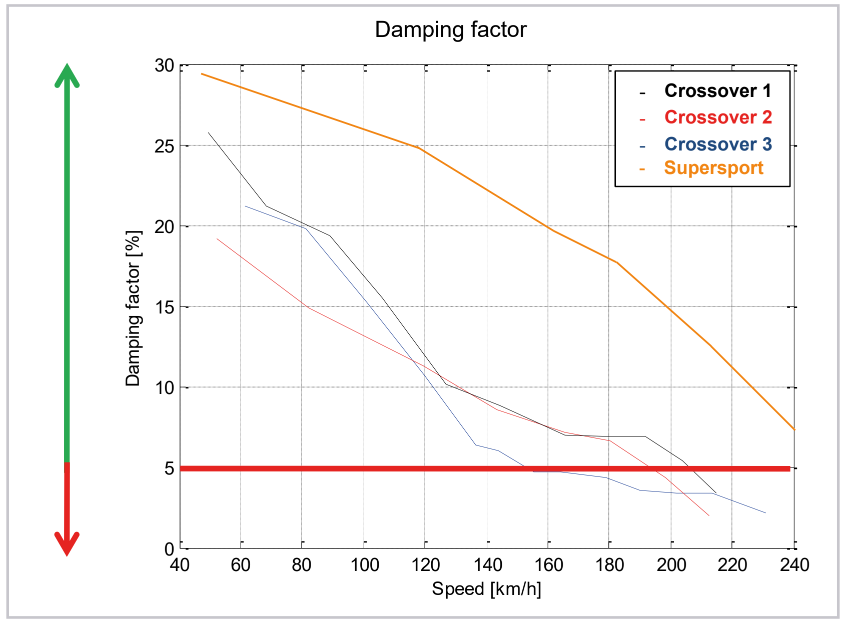


Figure 2: Calculated speed-dependent damping factor

Determination of a Damping Factor

Timely detection of the unstable oscillation modes of weave and wobble before the effects become uncontrollable is crucial for the effectiveness of semi-active damper systems. The determination of a calculable stability index is vital to this endeavor. The engineers from Soluzioni Ingegneria were therefore faced with the question of how such an index could be calculated from measured variables and what the critical limit is for dangerous instabilities.

To get to the bottom of this question, the engineers initially identified the phenomenon of instabilities in a motorcycle test. Various test riders performed stationary tests with a test vehicle equipped with measuring technology at staggered speeds. Hip movements were used to provoke instabilities. The analysis of the measured signals showed that a gyroscope is very well suited to capture the beginnings of weave and wobble. Its signals indicate typical oscillations from which a damping factor can be calculated as an instability index.

Figure 2 shows the damping factor calculated from the gyroscopic signals over the speed for three crossover bikes and one supersport bike. From the subjective assessment of the riders, a threshold of 5 % was determined. If the damping factor drops below this 5 % threshold, riding is perceived as dangerous. This threshold applies to laden motorcycles as well. In this case, the 5 % threshold is even reached at lower speeds.

Development of the Damper Control Unit

Now that the engineers had developed a measurable criterion for riding stability, comprehensive sensitivity studies on weave and wobble were performed in simulation. This was done using a non-linear motorcycle model with 12 degrees of freedom that was developed in MATLAB. The objective of these investigations was to understand how various design parameters of the motorcycle basically affect riding stability.

A solid design is fundamental to the riding stability of a motorcycle but particularly in the case of crossover motorcycles, suspension developers are confronted with significant target conflicts. Crossover motorcycles have to be designed for a wide variety of conditions such as changing friction coefficients between the road and the tires, tire wear or the load carried. Therefore, the objective pursued by the engineers from Soluzioni Ingegneria was to better absorb these target conflicts by means of a semi-adaptive suspension. Built on an onboard diagnostic system, a basically well-designed motorcycle was to be further enhanced by a control system.

In sensitivity studies, the damping of the handlebars was identified as a tunable parameter, as it is possible to influence weave and wobble with the steering damper in cornering as well as in straight-line riding.

Figure 3 shows the control logic that was developed. It is based on real-time acquisition of the gyroscope signals from which the damping factor is calculated. If this factor for weave and wobble is below the 5 % threshold discussed above, damping is intensified by the amplification factor K.

Validation in Virtual Test Driving

The effectiveness of the developed control system was tested with MotorcycleMaker. MotorcycleMaker has been specifically designed for the development of motorized two-wheelers and transfers real-world road testing into a virtual environment. For this purpose, MotorcycleMaker comprises a complete model environment consisting of an intelligent driver model, a detailed vehicle model and flexible models for the road and traffic. The vehicle model is based on an efficiently implemented, non-linear multibody system and includes a special tire model with large camber angles and transient tire behavior.

MotorcycleMaker is an open integration platform with various interfaces in order to integrate models as well as real-world components. The developed controller model was integrated into the virtual vehicle via the Simulink interface of MotorcycleMaker. This made it possible to comprehensively investigate the control system in various riding

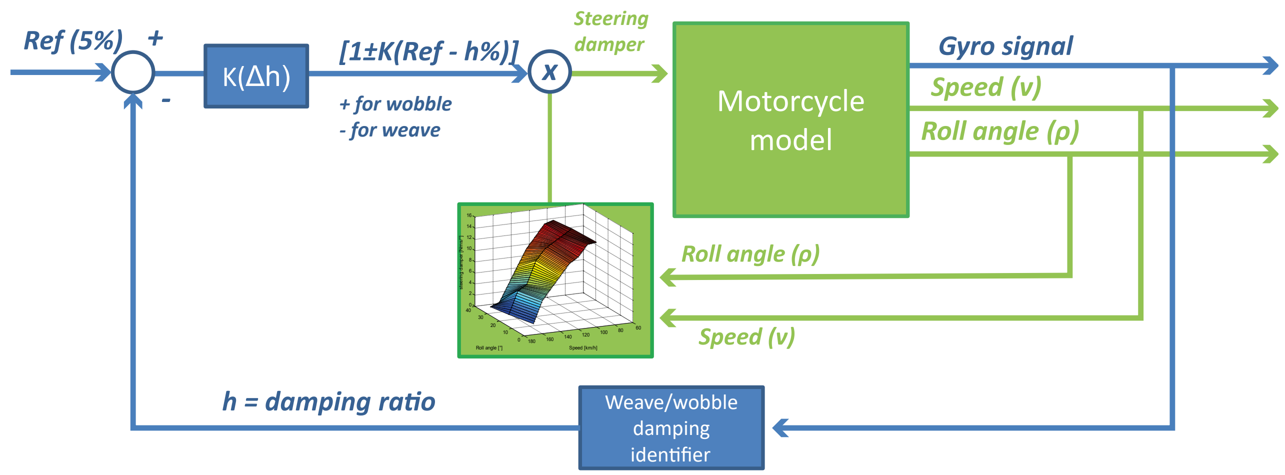


Figure 3: Logic for controlling the steering damper

maneuvers. The advantages of these virtual tests are obvious: They are exactly reproducible and non-hazardous. Especially for motorcycles, tests can be performed in the virtual world that would not even be possible on a test track at all. Whereas real-world tests would have to be stopped as soon as indications of weave and wobble occurred, the tests in MotorcycleMaker can continue until the motorcycle is no longer controllable by the rider.

Figure 4 shows a video screenshot of an open-loop maneuver with a fully laden motorcycle. The vehicle travels on a straight-line path at constantly high speed. Due to steering torque impulses, perturbations are imposed in order to provoke unstable handling.

Figures 5a) shows the efficiency of the integrated controller compared with a motorcycle without a controller. Furthermore, the figures show how the selection of the amplification factor affects riding stability. The control system using an amplification factor of K=0.2 is more effective than control without amplification (K=0). However, if the amplification factor is set from 0.2 to 1, the control system is unable to reduce weave. In addition, within a certain range, it leads to wobble.

Conclusion and Next Steps with MotorcycleMaker

The investigations with MotorcycleMaker show that controlling the steering damper makes it possible to reduce the instabilities of weave and wobble in a wide speed range on a straight path and in cornering. However, the selection of the appropriate parameters, in this case the amplification factor, is decisive for the effectiveness of the control system.

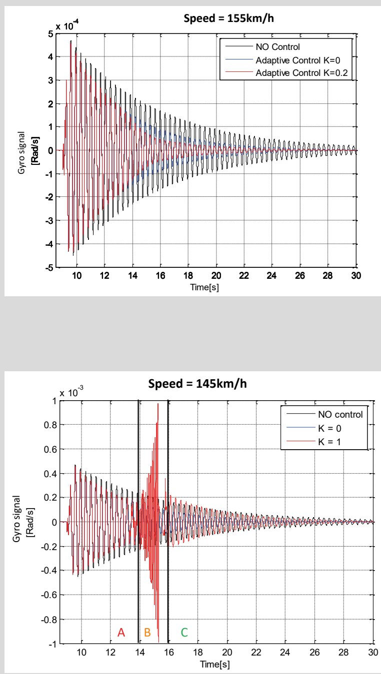
A targeted investigation of weave and wobble on a test track is very difficult because the instabilities can hardly be reproducibly generated in real-world testing – not to mention the potential risk of falls. Even minimal lane deviations, smallest steering corrections by the rider or minor variations of vehicle speeds can cause completely different, or even non-critical, handling. The vehicle dynamics simulation with MotorcycleMaker is therefore an important tool for systematically optimizing the riding stability of motorcycles. The simulation saves time and costs and enables non-hazardous testing of any conceivable parameter combinations.

The engineers from Soluzioni Ingegneria intend to conduct further studies to investigate the influence of tire wear on the riding stability of a motorcycle, among other things. From the findings gained by means of simulation, it is planned to research how this factor may be integrated into the control system.

Following comprehensive model-in-the-loop tests, a hardware-in-the-loop test bench is planned to be set up for the integration of a real-world steering damper and the real-world ECU of the newly developed control system. This will enable reproducible testing of the real-world components even within the limit range of vehicle dynamics in virtual test driving with MotorcycleMaker.

In summary, it can be stated that MotorcycleMaker seamlessly assists the engineers from Soluzioni Ingegneria in precisely investigating the correlations and interactions in the suspensions of modern motorcycles. Control systems to enhance riding stability can be validated with extreme efficiency at any stage of the research.

Figure 4: Test in the critical range of vehicle dynamics



Figures 5a) and b): Time curve of weave with various amplification factors of the control system