SEMI-ACTIVE SUSPENSION IN MOTORCYCLES

Motorcycles are increasingly designed for use both on the highway as well as off-road. To fulfil the different requirements in terms of comfort and stability as well as in the area of vehicle dynamics, KTM has developed a semi-active suspension. This has provided the basis for further innovations in the networking of motorcycle control systems.

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EXTENDED APPLICATIONS

For the past few years, the trend in motorcycle development has been increasingly moving in the direction of super tourers such as the model KTM 1290 Super Adventure with 118 kW (160 hp) that combine the engine power of superbikes with the wheel travel of an enduro (The KTM 1290 Super Adventure has 200 mm of suspension travel both in the front and rear wheels).

This development also expands the applications to which the vehicle is suited, from light to heavy-duty off-road, to very sporty highway riding. This trend subjects the vehicle chassis to enormous challenges. And this is not just in terms of the on-going compromise of comfort versus stability; it also concerns vehicle dynamics.

SYSTEM ARCHITECTURE

With regard to semi-active suspensions aside from different designs in valve hardware, vehicle manufacturers also pursue different systems in terms of the architecture and control strategy. The hardware design that KTM is pursuing, ❶, is used in the KTM 1290 Super Adventure model, as well as in the KTM 1290 Super Duke GT.

Thereby the vehicle is equipped with two single-axis accelerometers for the semi-active suspension. Each of these accelerometers measures body acceleration directly above the respective suspension elements. The wheel travel is measured directly using a sensor in the left fork tube. An advantage of the front wheel travel sensor is that the absolute wheel position in relation to the body is always directly known. This makes it possible to estimate the load, or to implement a software-controlled hydraulic end stop function.

The wheel travel is measured indirectly for the rear wheel. To this end, an angle sensor is used for the contactless measurement of the swing arm angle using the Hall Effect principle. This angle-dependent sensor value is converted into wheel travel in the suspension control unit. The advantage of this design is good integration in the vehicle, and resistance to external environmental conditions.

The fork has a split design. A sensor and a spring are located in the left fork tube, while a damper unit with a valve is located in the right fork tube. The shock absorber, which has a mono tube design, supports the valve in the damping unit. The position sensor on the shock absorber, as described above, is located externally on the swing arm.

The input signals are converted into the damping force requirements in the suspension control unit (SCU). The calculation times for tasks may be as fast as 2 ms, wherein the damping requirement is updated at 250 Hz.

CONTROL STRATEGIES

Aside from possible differences in the hardware, the control strategies are the unique selling proposition of each semi-active suspension system on the market. In the first generation of semi-active suspension, KTM essentially opted for strategies such as the sky-hook, anti-dive, anti-squat, load recognition, and stroke dependence in order to negotiate the classic tasks of achieving comfort, traction, and vehicle dynamics.

Sky-hook control is an approach that comes from the automotive industry [1]. In principle, the required damping force is determined on the basis of body movement and wheel movement, the weighting of which is scaled based on a factor, α, Eq. 1:

Eq. 1 $$F_{Damper} = ((1-\alpha)\cdot v_{Body} + \alpha \cdot v_{Wheel}) \cdot c_{Sky\text{-}hook}$$

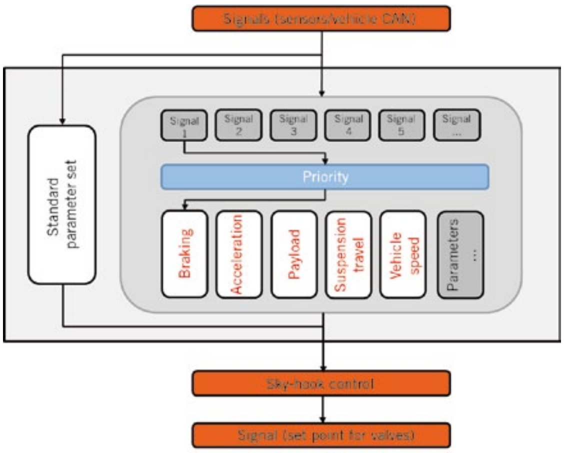
KTM uses two independent controllers for fork and spring damping. The hydraulic anti-dive function minimises pitch tendencies, in particular in vehicles with long wheel travel and a high centre of gravity.

Pitch compensation during braking is implemented by switching the parameters of the sky-hook approach. This switching is controlled by means of an activation threshold of the brake pressure signal and the brake pressure gradient of the front wheel brake, as well as by prioritising the different strategies, ❷.

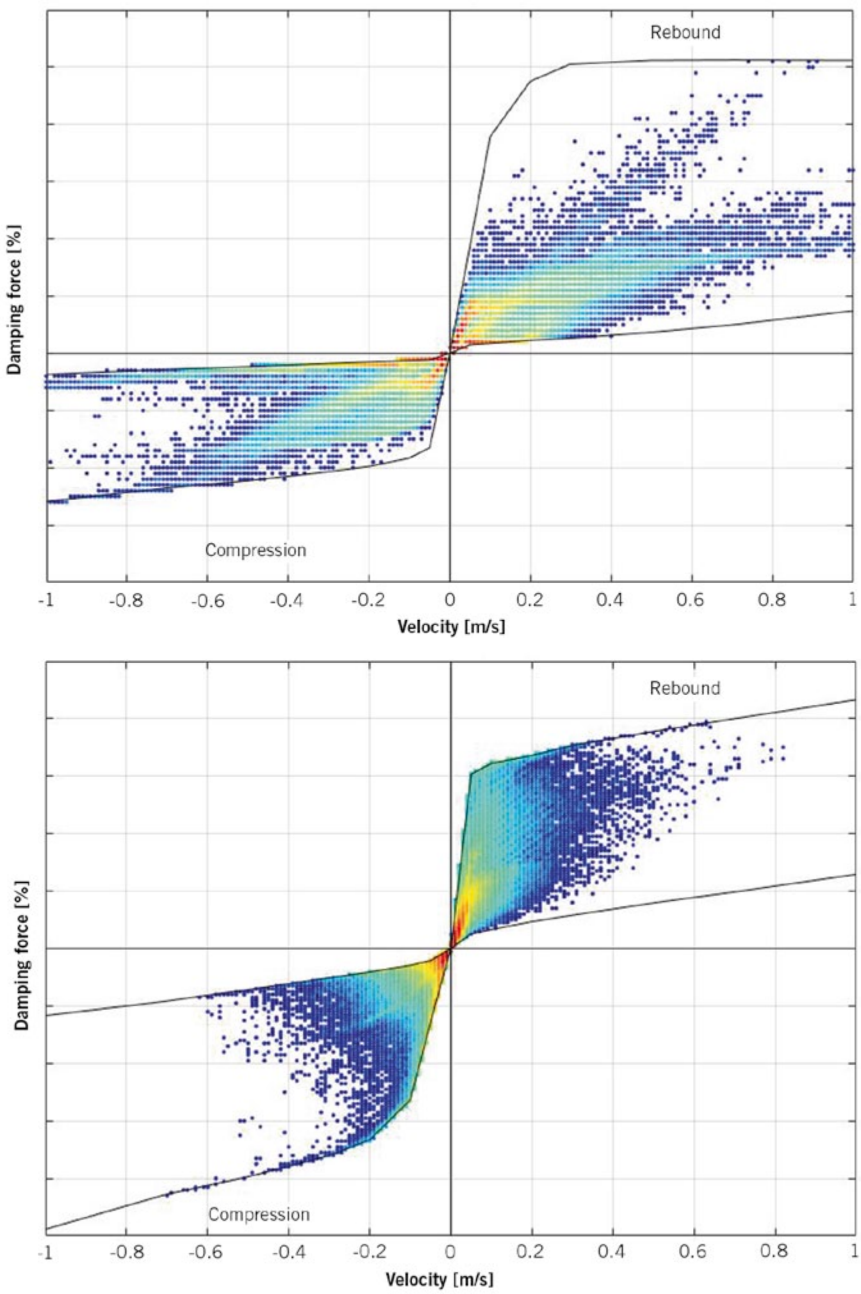
The anti-dive function makes use of the special properties of the WP semi-active suspension elements, which are able to implement high damping forces even in the case of very low stroke speeds, ❸.

The total available damping map is therefore identical for the KTM 1290 Super Adventure and the KTM 1290 Super Duke GT. However, the vehicles differ significantly in terms of application, and as a result, the map is used differently depending on the type of vehicle and the function parameters.

❶ Sensor design, KTM 1290 Super Adventure (© KTM | Mitterbauer)



❷ Parameter switching diagram (© KTM)



❸ Use of the damping map for dynamic highway riding (top: fork; bottom: shock absorber) (© KTM)

OUTLOOK FOR SEMI-ACTIVE SUSPENSION

The first development approach when introducing the semi-active suspension to the world of two-wheelers was based on adopting the sky-hook principle from the automotive industry. This initial step could be described as "comfort"-oriented, wherein body acceleration represents the primary criterion for this approach.

Riding tests during the early development phase at KTM revealed that this approach was not entirely satisfactory in terms of vehicle dynamics of a motorcycle. For example, the influence of a high roll angle on the acceleration of the vehicle's vertical axis, as well as the high fluctuations in wheel load when quickly changing directions posed significant challenges when relying exclusively on a sky-hook approach.

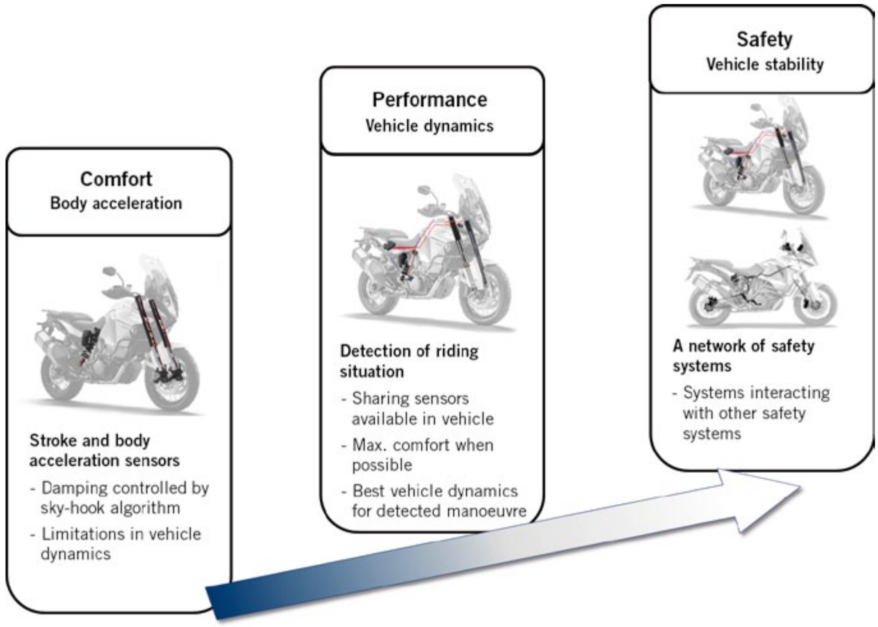
The next development objective was to increase "performance", in order to improve vehicle dynamics. To this end, additional sensors in the vehicle, such as brake pressure sensors, were used in order to correctly interpret the riding situation. Starting from this basis, the system can be applied in such a way as to maximise comfort as long as the riding state allows this. If specific riding manoeuvres, such as a rapid change in direction, are detected, the control unit automatically switches the application parameters in order to ensure optimal vehicle dynamics. This is currently the state-of-the-art in terms of semi-active suspension control systems in the motorcycle industry. Starting from this level of development, the next logical step – after "comfort" and "performance" – is the integration of semi-active suspension and its sensors in the topic of "safety".

Here, vehicle stability is a decisive criterion for body acceleration and vehicle dynamics, ❹. In order to achieve this objective, it is necessary to link safety systems with one another.

VEHICLE NETWORKING

The list of electronic vehicle control systems in two-wheelers is long and has developed rapidly in recent years: launch control, engine control, ABS, quick shifting, slip control, wheelie control, motorcycle stability control, traction control, cruise control, hill-hold control and the semi-active suspension. This networking of these vehicle control systems is precisely the challenge faced by the development for motorcycles in the future.

Each of these systems reacts to a specially recognised riding situation, and adjusts the actuators of the engine, brakes, and chassis accordingly. The main development priorities associated with this architecture are the unambiguous recognition of the riding situation, as well as the speed and quality with which the riding situation is detected. Moreover, the coordinated measures of multiple separate systems have the potential to increase the efficiency of the control systems.



4 Stages of development for semi-active suspension in conjunction with the entire vehicle (© KTM | pictures Mitterbauer)

SAMPLE APPLICATION HIGHSIDER

A highsider is a situation in which the rear wheel of a motorcycle suddenly starts to skid but then regains traction, causing the rider to be literally catapulted out of their seat [2]. A highsider represents a dangerous instability that very often results in a fall.

The semi-active suspension is able to detect a skidding rear wheel in an inclined position only under certain circumstances and with a delay by detecting the wheel travel. This critical riding state is more efficiently detected and terminated by traction control. Vehicle stability can, however, be increased using semi-active suspension if the traction control has active access to the chassis, since, for example, it is expected that a torque reduction will restore traction and thus cornering force in the rear wheel. The resulting compression could be counteracted by increasing damping in the rear wheel, thus reducing further fluctuations in wheel load.

CHALLENGES FACED IN VEHICLE NETWORKING

Motorcycles are equipped with control units from different sectors and from different suppliers. On the one hand, the developers of these control units have expertise in their relevant fields; on the other hand, in the past, they have provided few, if any, interfaces for other control units. Holistic system architecture is lacking.

The goal of KTM is to develop coordinated communication between the individual control systems. In doing so, a riding situation in which control is needed must be unambiguously detected using all available sensors. This is the only way to achieve a coherent strategy for vehicle stabilisation in the event that instability arises. In general, two approaches are feasible in the future which can follow on from one another.

In a first step, there is the retention of the current vehicle architecture with dedicated control units, but with a vehicle sensor cluster and cross-system control of the actuators. The focus of development is determining a leading system in terms of unambiguously identifying the riding situation and the reactions and the prioritisation derived therefrom when controlling the actuators. This system architecture poses an enormous challenge, when integrating development partners and their communication interfaces.

In the subsequent generation, a 'mastermind' in the form of an electronic control unit (ECU) for the entire vehicle will be introduced, to which the existing control units will be subordinated as slave devices. This ECU for the entire vehicle will assume the core functions of existing control units. From today's perspective, this would require an extraordinary disclosure of know-how and the transfer of knowledge between suppliers. A secondary effect of the electronic control unit for the entire vehicle is that individual control units would become superfluous. The hardware drivers will be integrated directly into the actuator assembly and controlled by the ECU for the entire vehicle.

These aspects make the development of the semi-active suspension, as the newest of the above-mentioned control systems, a very interesting field of future development and open up new potential for vehicle safety and vehicle dynamics.

REFERENCES

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[2] Stoffregen, J.: Motorradtechnik – Grundlagen und Konzepte von Motor, Antrieb und Fahrwerk. 8th edition, 2012, Springer Vieweg, p. 321