

Semi-Active Suspension, Extending the Limits

Alexander Alonso Torres

1 Introduction

The avalanche of SUVs and the arrival of autonomous driving are pushing vehicle manufacturers to improve ride-comfort compromise during last years. Semi-active suspension is a very powerful tool that increases considerably vehicle behavior comparing with a standard one. Although there are some limits, studying each application carefully these can be extended.

In the last years KYB has developed a semi-active suspension system, and it's now entering into the market as TIER1, as a complete system shock absorber & software supplier. During the development KYB has manage to solve some limitations related to lack of robustness and noise. This will be the case study for this article.

2 Semi-Active System Architecture

Semi-Active System architecture is built by four level sensors, three G-sensors, an ECU (“Electronic Control Unit”) and one actuator on each shock absorber.

Working principle of the system is defined in three steps following the general rule Sense > Define > Act. The level sensors measure wheel – body relative displacement for each wheel and the G-sensors located on the car body, two of them on the front axle and the third one on the rear are in charge of measuring the vertical accelerations. These measured signals from sensors added to many other information available directly from the CAN Bus (such as vehicle speed, steer wheel movement, longitudinal and lateral acceleration, braking status, others…) are treated as input for the ECU control strategy. Each 2ms software

control strategy analyses vehicle status by reading input signals. If needed the ECU transmits an output current command to each shock absorber actuator in order to increase each damping force and correct/adapt vehicle dynamics deviation. See Fig. 1.

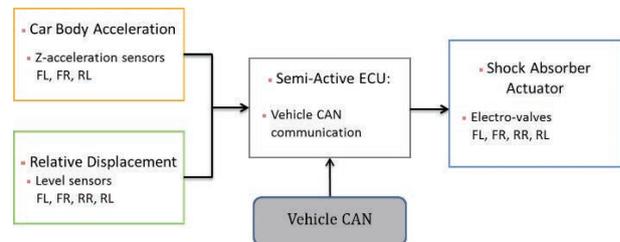


Fig. 1 System Architecture

From shock absorber point of view, the standard technology has been combined with a fast response electro valve. The aim is to adapt the damping force – piston speed system to a damping force – piston speed – command current dependent system. See Fig. 2.

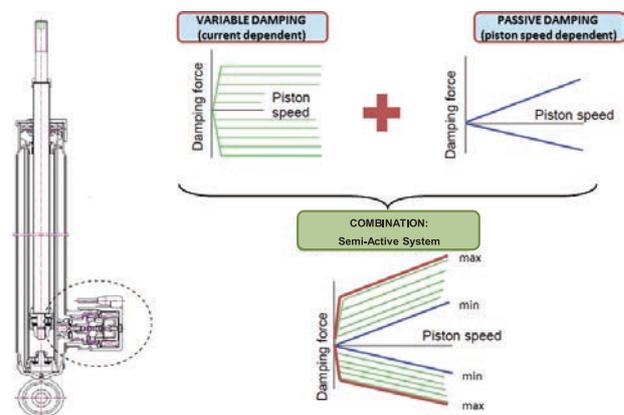


Fig. 2 Damping force, piston speed and command current dependent system

3 Semi-Active Control Strategy

During driving life, Semi-Active system will need to manage many different situations. By mixing vehicle status with driver and road inputs, all these life situations are collected and Semi-Active control strategy must be able to cover all of them. See Fig. 3.

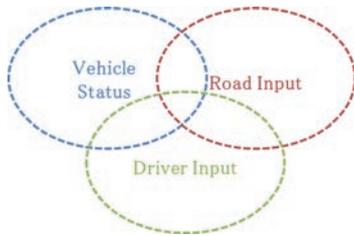


Fig. 3 Vehicle driving live situations

For the purpose of this study pure driver input live situations have been discarded. So from now on, we will focus just on road input cases. See Fig. 4.

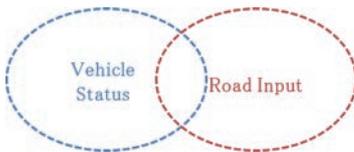


Fig. 4 Vehicle driving live situations simplified

Vehicle behavior must accomplish three main targets (Fig.5) and each of them is ensured by some functions or tools as described in Fig. 6.

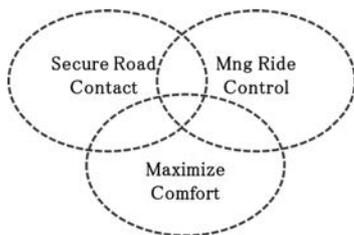


Fig. 5 Vehicle behavior targets

For safety reasons highest priority target is to secure road contact. For this, a base minimum damping has to be set. This is handled by “Base Current” function and basically it applies a current command depending on vehicle speed.

To provide robustness to base damping in case of abrupt bumps and wheel hopping, “Anti Wheel Hop” function increases the command current

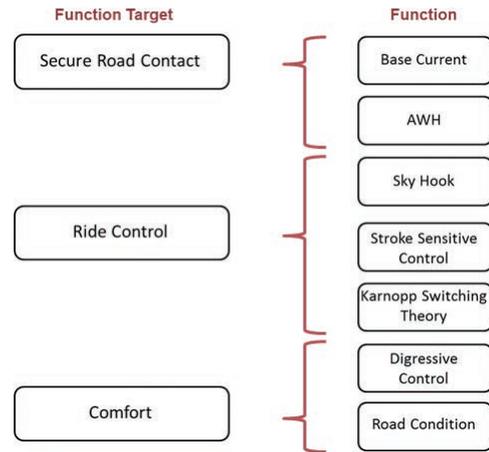


Fig. 6 Sw strategy functions for road inputs

during a period of time. This function detects wheel hopping case and adds a step of current to fix it. See Fig. 7.

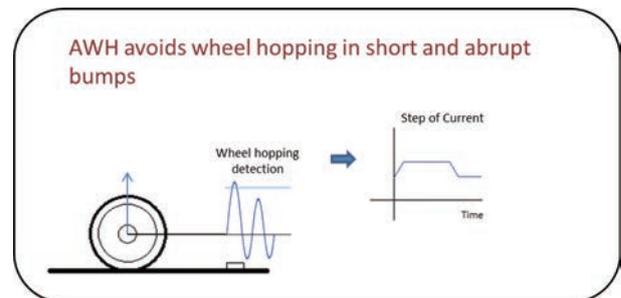


Fig. 7 Anti Wheel Hop Function description

Once minimum safety conditions have been established, control strategy is set to manage ride control. “Sky Hook” theoretical function has been chosen for this purpose. See Fig. 8.



Fig. 8 SkyHook functionality

As described in system architecture description, Semi-Active system has three G-sensors distributed in vehicle body in charge of measuring bounce, pitch and roll body rates. See Fig. 9.

After calculations using bounce, pitch and roll rates, vehicle speed signal and vehicle tuning parameters, Sky Hook function provides a continuous damping command to the system (Fig.10).

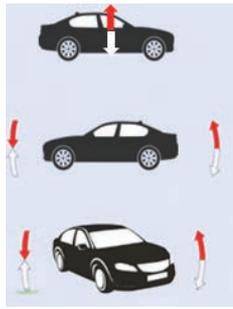


Fig. 9 Modal Speeds: Bounce, Pitch and Roll

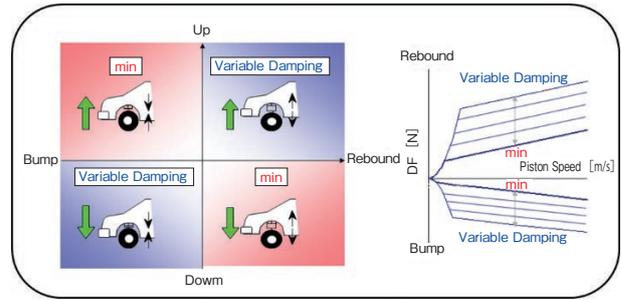


Fig. 12 Karnopp Switching Theory Description

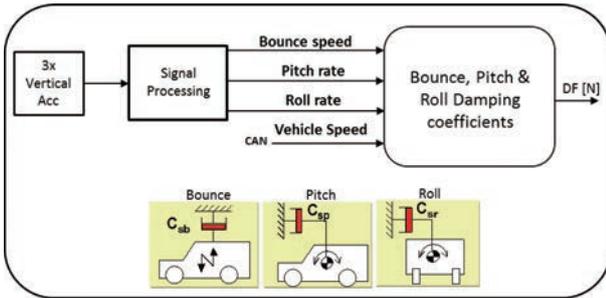


Fig. 10 SkyHook function DF calculation

In order to increase ride control efficiency at end stroke, the “Stroke Sensitive Control” function gain multiplies Sky Hook damping force command. See Fig. 11.

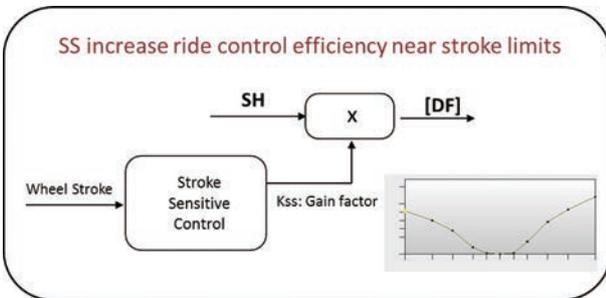


Fig. 11 Stroke Sensitive Function DF

Until this point, a continuous damping command has been provided to achieve ride control. In order to warranty vehicle flat behavior, the wheel and body relation movement sense has to be taken into account. For this purpose, software designer needs to consider the “Karnopp Switching Theory”. See Fig. 12.

Body and wheel vertical displacement combination can be split in four different cases: body up and wheel in compression or rebound, body down and wheel in compression or rebound.

For cases 1 and 4, Semi-Active control strategy sets minimum damping force in order to recover

the reference position as soon as possible, while during cases 2 and 3 it is allowed to adjust the damping according to the damping command defined until now.

Taking a look to following road input example (speed breaker), a clear effect of “Karnopp” function can be seen. See Fig. 13.

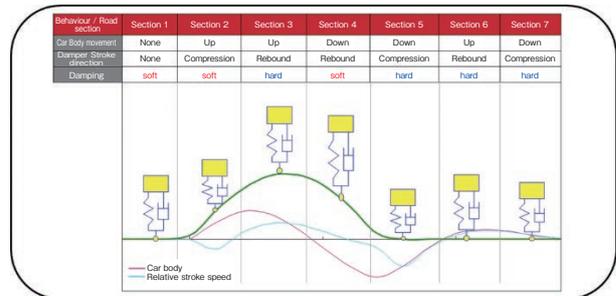


Fig. 13 Karnopp Switching Example

Once having managed body control, it’s time to take a look to comfort and increase the filtering. “Digressive Control” is responsible to decrease variable damping in case of impacts throw aggressive road inputs. See Fig. 14.

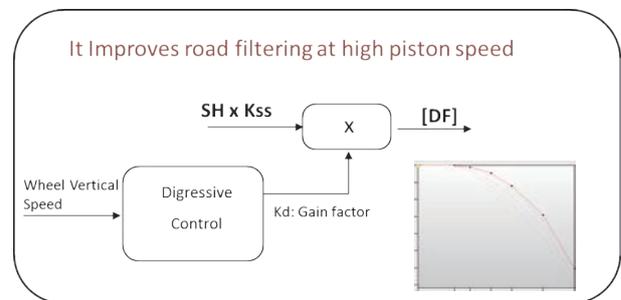


Fig. 14 Digressive Control Function DF calculation

This simple function is very efficient in case of single input, but for continues road inputs, what usually it’s call “rough road”, Semi-Active control strategy uses a last function called “Road

Condition”. See Fig. 15.

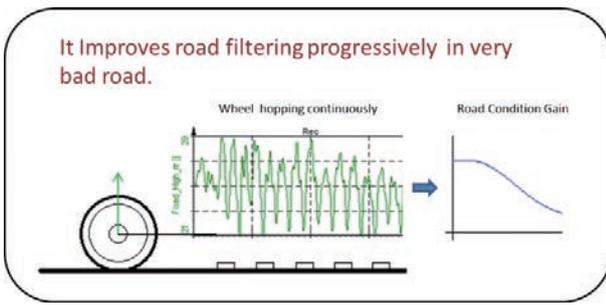


Fig. 15 Road Condition Function Description

If continuous wheel hopping happens, the function adapts requested variable damping progressively until having the desired filtering.

4 Theoretical Strategy Limitation

Highest limitation of semi active suspension is the non-possibility to predict road inputs. Nowadays autonomous driving technology is providing many different solutions of preview systems, but even combining some of them, they are not robust enough to work properly 100% of driving time. This means that Semi-Active system must cover robustly all live situations by itself. To be considered that no preview systems have been taken into account during this case study.

As the spring properties can't be adapted, and time consumption for movement stabilization is needed, an optimization by "Karnopp Switching" function has to be done by applying a minimum damping in some maneuver steps.

Let's imagine a worst case, comfort oriented vehicle, with short stroke shock absorbers and the lack of damping in some steps according to semi active suspension functionality, this implies a high risk of impact noise and lack of body control in aggressive road inputs, for instance, speed breakers or down steps.

Fig. 16, shows a real case study measurement, where some rebound end of stroke impacts can be seen just in the last down steps.

During this test the last 4 steps of 70mm height have been enough to trigger rebound end of stroke impact noise. This fact is very clear in downstairs right graphic, force vs displacement, where some force peaks appear just at the end of

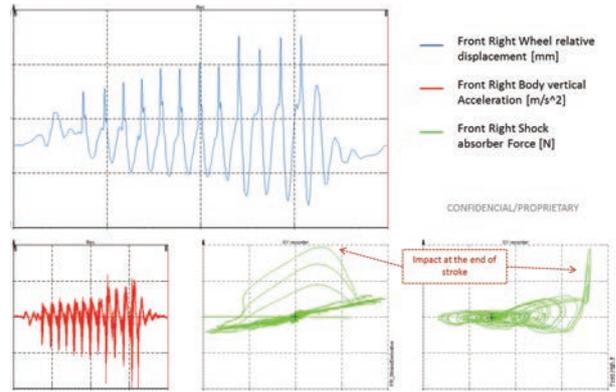


Fig. 16 Down Steps track, with rebound end of stroke impact noise example

rebound stroke (positive).

5 Studied Solutions

In order to solve the issue, two different solutions have been tested. First one, based on a passive solution, a HRS ("Hydraulic rebound stopper") system have been used. See Photo 1 and Fig. 17.



Photo 1 HRS

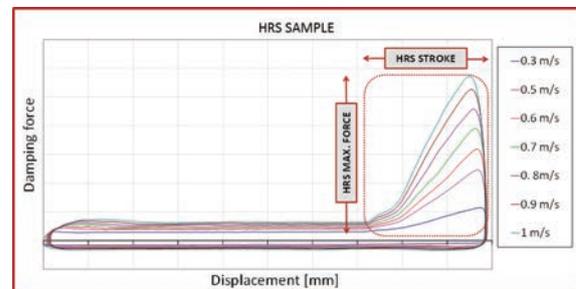


Fig. 17 HRS Damping force characteristics

Basically, using a deformed inner tube and a plastic segment located in piston rod, a new chamber is created in rebound side, and it is increasing damping force according to piston

speed and rebound stroke.

This is a fantastic solution to improve shock absorber efficiency at the end of rebound stroke because it absorbs a great quantity of energy, fast and progressively.

On the other hand, the implementation of this system has an important cost impact on shock absorber price.

The second solution tested, has followed same HRS philosophy, but in this case, it has been implemented modifying software control strategy. So, a new function has been implemented, and called DHS (“Double Hydraulic Stopper”). See Fig. 18.

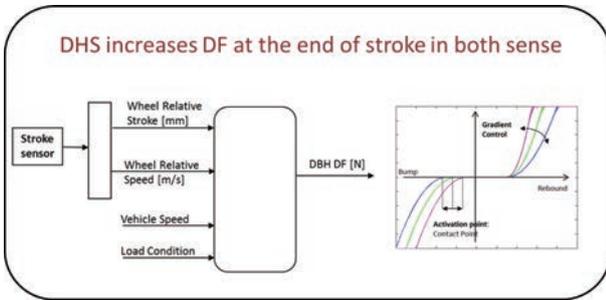


Fig. 18 DHS function DF calculation

The function adapts the damping command (activation point and gradient) according to vehicle speed and load condition.

DHS function avoids end of stroke impact noise and provides robustness to ride control in

aggressive road inputs as speed breakers or down steps. See Fig. 19.

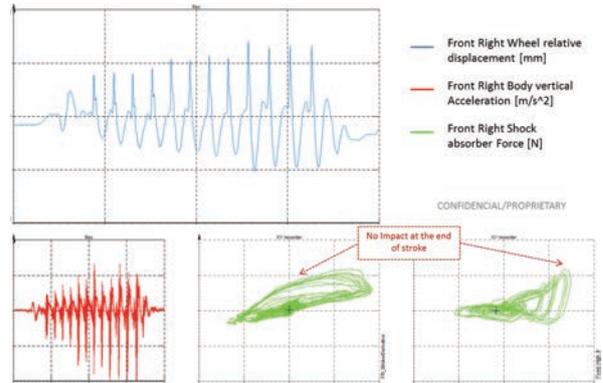


Fig. 19 Down Steps track, without rebound end of stroke impact noise

6 Summary

KYB provided two different solutions to solve impact noise and lack of ride control in aggressive road inputs as speed breakers. Finally the customer decided to go on with DHS software solution. See Fig. 20.

By intelligent combination of theoretical strategy and experimental function, KYB has managed to improve noise filtering and avoid extra cost to our Customer. Studied solution has been implemented in mass production software strategy.

KYB is now extending the limits of the system in

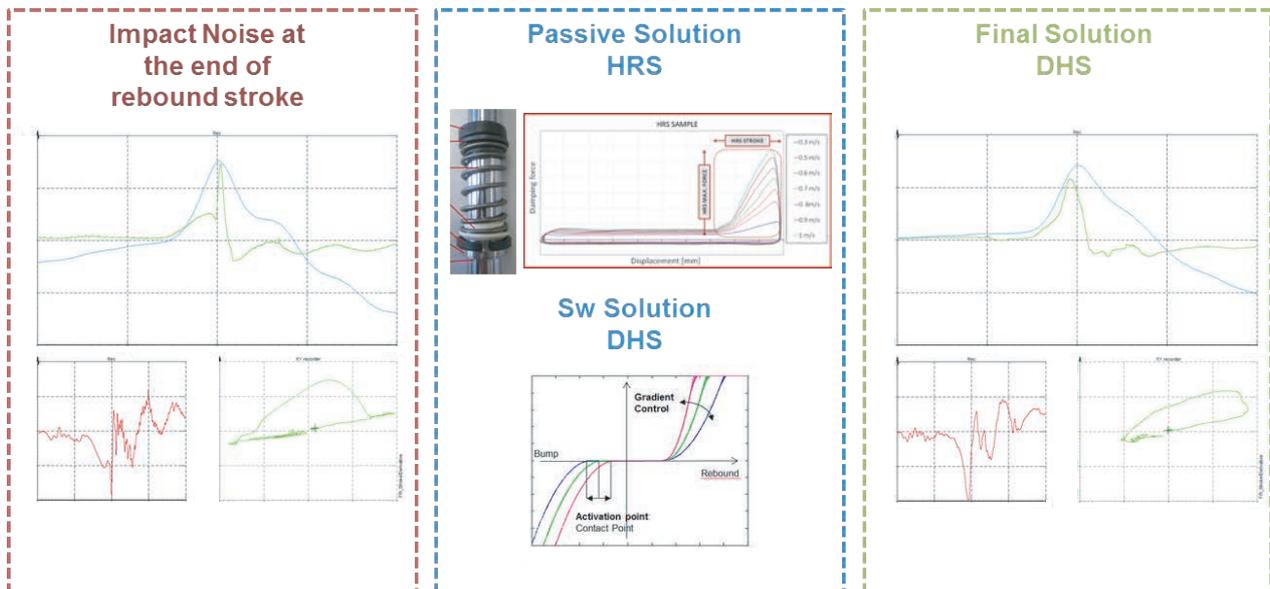


Fig. 20 Summary

order to enhance even more the body control and comfort level as expected from such an intelligent technology, KYB's Semi-Active Suspension.

We believe that providing solutions to specific requirements as in this project we also led to build up our know-how and expertise on E/E (Electrical/Electronics) system development. We

would like to take advantage of this experience to continue adding value to electronic controlled system which seems to be the future.

Last but far from least, I'd like to express my sincere appreciation to my colleagues great cooperation during this project development.

Author



Alexander Alonso Torres

Joined company in 2012.
Currently at KYB Europe GmbH
as Semi-Active suspension team
calibration and vehicle testing
engineer.