Slender Comfort Vehicles: Offering the Best of Both Worlds

Brink Dynamics has developed a new tilting technology (DVC) that enables the existence of a new class of vehicles, thus opening up attractive market opportunities for the automotive industry. The Carver, the first tilting Slender Comfort Vehicle (SCV) in series production, has recently achieved European Road Certification.

SCVs combine the positive characteristics of a car with the positive characteristics of a motorcycle

The Concept

For the past thirteen years, Brink Dynamics has been developing a new class of tilting three-wheel vehicles, which they have named SCV "Slender Comfort Vehicles". Being slender and comfortable, SCVs combine the positive characteristics of a car (high safety, comfort and luxury) with the positive characteristics of a motorcycle (a low weight and dynamic driving performance). These vehicles have been proven to show an excellent and inspiring driving behaviour and outperform most cars in agility and cornering, while easily beating motorcycles on comfort and safety. The tilting behaviour, which is essential to keep the narrow vehicle in balance, also adds an extra dimension to its driving behaviour, which is appreciated by many customers.

The tilting behaviour of SCVs adds a new dimension to passenger transportation and provides the driver with a positive driving experience every time. This, amongst several practical benefits, is one of the main selling attributes of this new class of vehicles.

Market for SCVs

In the past decades, the automotive market has changed to a narrow-margin commodity business, in which the traditional market differentiators such as performance, number of defects and safety have been overtaken by other less rational selling attributes. Consumers are focusing more on more on emotional and representative product attributes – for example, whether the car is fun to drive, well designed and stylish, and whether it reflects the right lifestyle. SCVs are fun to drive, and when brought to the market with the right approach they are likely to appeal to a large number of people. Figure 1 shows an artist's impression of three typical examples of possible SCV classes that could serve different market sectors.

An extensive market study has revealed that SCVs have a significant market potential, exceeding 10 million vehicles per annum. Similar to the conventional car market, several classes of SCV can be envisioned, each serving certain target groups and lifestyles.

Technological Challenge

Designing a tilting slender vehicle requires a non-conventional approach. When the width of a car is reduced by half, cornering becomes a problem, as slim vehicles are more prone to fall over, Figure 2. Of all the possible approaches, tilting when cornering is the best option. This is actually what a two-wheeler does, and is nothing new. However, if one wishes to have the comfort and safety of a car, the vehicle needs to have an

Figure 1: An artist's impression of three possible SCV versions, each corresponding to a different niche market and life style. Drawings by Johan Vissers

Figure 3: The Carver in action.

enclosed and solid passenger cabin. With such a cabin, the balance control cannot be left to the driver, as the vehicle becomes too heavy. Furthermore, drivers will have difficulties putting their feet out at low speeds to avoid falling over.

Therefore, an automatic system that takes over this balance control had to be created. As a result, designing a tilting vehicle is not a package design problem but a purely technological problem requiring the development of a sophisticated automatic balance control system. Such a control system needs to be capable of maintaining the ideal tilting angles under all imaginable driving conditions, such as at all speeds and accelerations and during rapid emergency manoeuvres, but also on slippery, irregular or slanting road surfaces. At the same time, it should also be predictable, intuitive and easy to use. Last but not least, it should be safe, reliable and fail-safe.

Breakthrough Invention

This challenge has led to the development of DVC (Dynamic Vehicle Control) technology. This system consists of a hydro-mechanical system that splits the steering input from the driver into a front-wheel steering angle and a tilting angle of the chassis. At varying speed and road conditions, the distribution between the front-wheel angle and tilting angle is always automatically adjusted, ensuring the optimum (balanced) situation under all circumstances [1, 2, 3].

At low speeds, the driver's steering input is fully directed to the front wheel, and the vehicle remains upright. At higher speeds, the input is more and more translated into a tilting angle and not into a front-wheel angle. As the DVC system uses a combination of hydraulic and mechanical technologies, it has high reliability, quick response and a natural "feel". The technology has been implemented into a commercial SCV vehicle called the Carver, Figure 3, and is currently commercialised by Vandenbrink B.V. in the Netherlands.

The distribution between the front-wheel angle and tilting angle is always automatically adjusted

Basic DVC Technology

The main elements of the DVC system are the DVC manifold and a pair of tilting cylinders, Figure 4. The tilting cylinders (2) are attached between the rear (non-tilting) part of the vehicle and the tilting front part of the vehicle (the passenger compartment) in such a way that activation of these cylinders causes a tilting action of the passenger compartment. The DVC manifold (1), which is a hydraulic valve acting as the main sensor, measures the torque of the steering wheel relative to the front wheel, and, depending on this torque, pressurizes the hydraulic oil to one individual cylinder (red fluid in Figure 4) and withdraws the oil

Luxury SCV

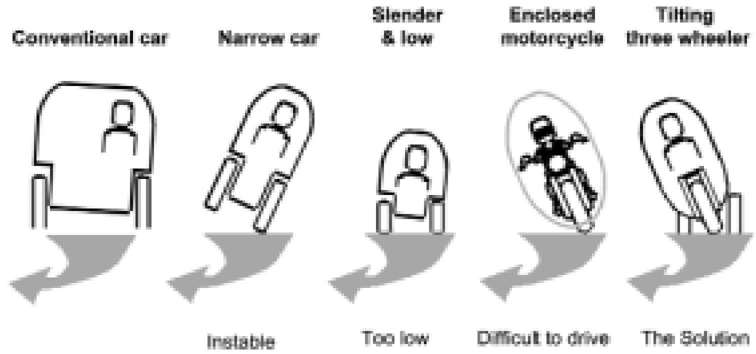
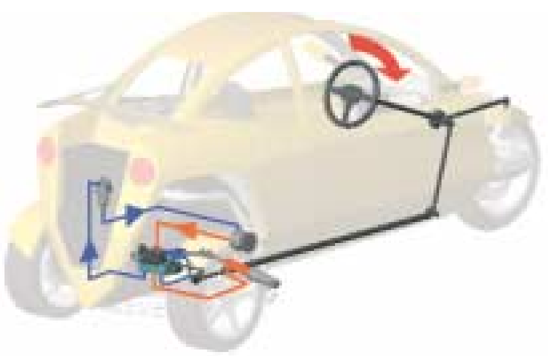
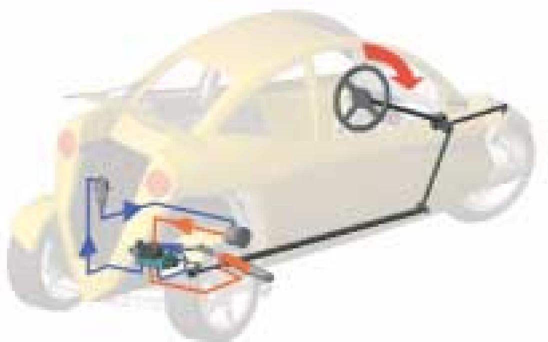


Figure 2: Tilting when cornering is the best option.

a) Upright, in balance;



b) Upright, with steering force;



c) 10° tilt, with steering force;

d) 30° tilt, in balance.

Figures 4 a – 4 d: When cornering, the DVC manifold directs hydraulic fluid to one of the cylinders, resulting in a balanced tilting action:

from the counteracting cylinder. The resulting tilting action will lead to the release of torque on the front wheel, causing the pressure in the system to relax to normal pressure (blue in Figure 4). As a result, the passenger compartment is always in dynamic balance.

The basic system described above works highly satisfactorily at speeds of between 10 and 100 km/h with low to moderate cornering dynamics.

Improvements to DVC Technology

This is schematically displayed in Figure 5. In order to expand the envelope under which the tilting system operates satisfactorily, several components and features have been added or integrated into the basic system.

1) A low speed switch that turns off the tilting action below 10 km/h. This system also acts as an emergency back-up system using a fully independent stand-by hydraulic control system.
2) Power steering for light and direct steering during vigorous steering actions at low speed (e.g. parking).
3) Tilting attenuation associated with speed to improve the transition between a non-tilting situation at low speeds and the tilting situation at high speeds.
4) Anti-steering torque for optimum vehicle agility and safety in vigorous steering situations at high speeds, such as lane changes or panic situations. This feature increases the promptness of the system and also lowers its power consumption [4].
5) Active rear wheel steering to optimise comfort and safety at high speed.
6) Banking Angle Feedback for continuous interaction between the driver and the vehicle, acting at all speeds.

Most of the above features and functionalities have been integrated into the hydraulic DVC manifold shown in Figure 6. This has the advantage that the tilting hardware has become rather simple: In addition to the DVC manifold and the cylinders, only a few other simple components are required to create a fully functioning system (Figures 6). The total weight of all components is less than 20 kg. The complexity of the system is comparable to hydraulic power steering systems currently employed in conventional cars.

The consolidated action of these features and components results in a driving performance that has a natural feel and is a pleasure to drive. The system has a large degree of freedom for tuning the characteristics of the tilting system. This allows adjustment of the overall character of the vehicle, enabling the existence of both aggressive and direct tilting vehicles as well as vehicles with a more comfortable and relaxed tilting characteristic.

The DVC system as employed in the Carver provides a maximum tilting angle of 45° and a maximum tilting speed of 82°/s. This tilting speed figure is an important characteristic, as it describes the promptness of cornering, especially in a chicane (lane change) situation. As a reference: on a conventional motorcycle, tilting speeds of this magnitude can only be achieved safely by highly experienced racing motorcycle drivers. The tilting function operates over the full range of 10 –180 km/h, the latter speed being the top speed of the Carver.

With the DVC system, vehicles can be designed with a width of 1 metre or even less. Due to the simple and straight-forward feedback system, the DVC system continues to function properly even when one or more of the wheels start to skid, as can happen on slippery roads (rain, snow, gravel). With extreme steering actions, this may even result in a spectacular breakaway of the rear wheels as also shown in figure 3. Under these conditions, the driver still has full control and does not have to fear falling or tipping over.

Unique Technology

Since 1920, many small and large engineering projects have been undertaken to create mechanisms

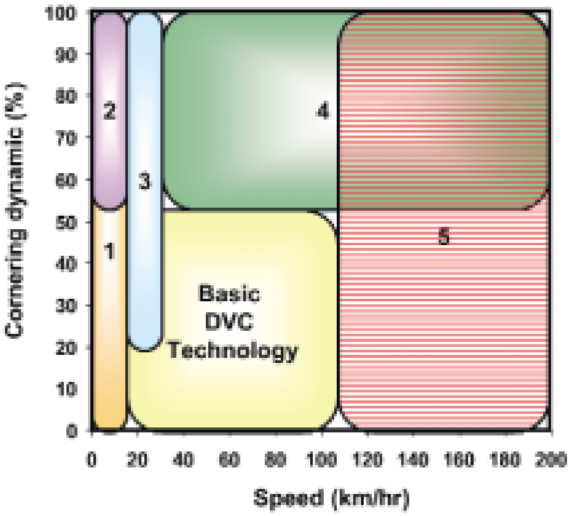


Figure 5: The additional technologies for widening the drivability envelope. This drivability area is schematically represented as a combination of driving speed and cornering dynamics. For example, bottom right represents highway driving, and top left represents dynamic cornering in the city.

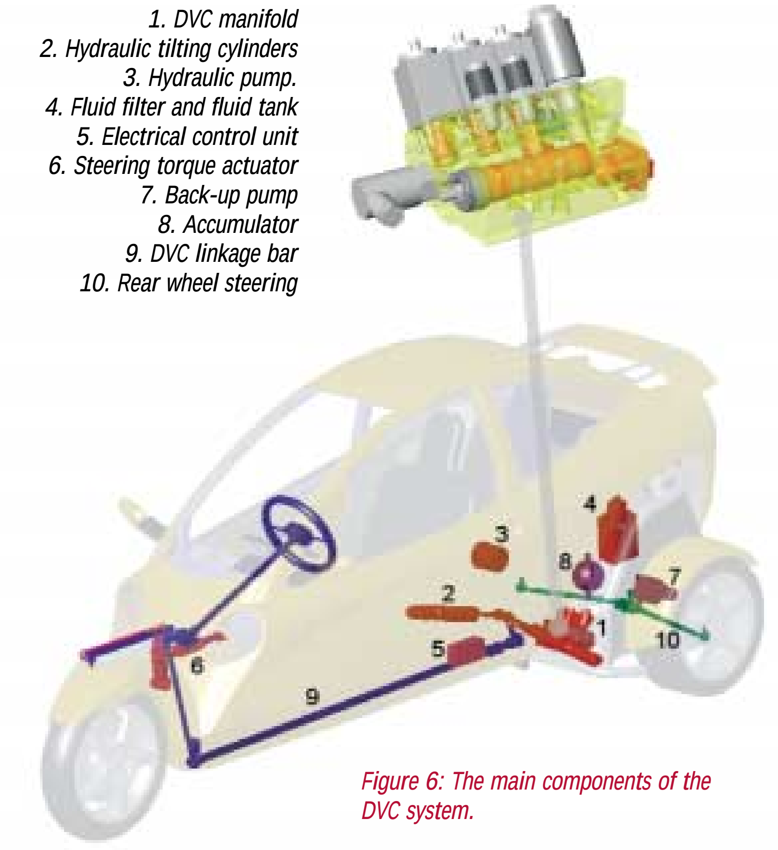


Figure 6: The main components of the DVC system.

for automatically tilting slender vehicles. Almost all car and motorcycle companies have made serious research efforts to create a practical SCV. None has led to a consumer-friendly vehicle with good driving characteristics that performs well under all normal practical driving conditions. The best overview of these attempts can be obtained from website references [5, 6]. From that perspective, DVC technology can be regarded as a unique technology.

DVC technology has enabled the development of the first commercially available tilting SVC, called the Carver [7,8]. Thanks to the robustness of the DVC system, the Carver has achieved full European type approval, also passing all the safety and emission tests. It also received highly positive reviews from customers and the automotive media.

Conclusions & Future Prospects

Thanks to DVC technology, tilting SCVs have now become a viable option for the transportation market. They show positive driving characteristics that are particularly positive on winding roads and in heavy traffic. In addition to these attributes, SVCs have lower drag and lower weight. SCVs thus have significantly lower fuel consumption and lower emissions compared to conventional cars. SCVs also take up less space in traffic and when parking, making them ideal city vehicles.

For these reasons, various car and motorcycle companies have recognized this new vehicle concept as a potential breakthrough to create a totally new market. These companies are now conducting feasibility studies in this area.

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[1] van den Brink, C.R. and Kroonen, H.M.: Dynamic vehicle control for enclosed narrow vehicles. In: Volume I EAEC 6th European Congress "Lightweight and small cars: The answer to Future Needs (1997). Pp. 217-226

[2] van den Brink, C.R.: Realization of high performance man wide vehicles (MWVs) with an automatic active tilting mechanism; In: Proceedings EAEC European Automotive Congress "Vehicle Systems Technology for the Next Century: Conference II – Vehicle Dynamics and Active Safety", Barcelona (1999); pp. 41-49

[3] Pauwelussen, J.P.: The Dynamic behaviour of man-wide vehicles with automatic active tilting mechanism. In: Proceedings EAEC European Automotive Congress "Vehicle Systems Technology for the Next Century: Conference II – Vehicle Dynamics and Active Safety", Barcelona (1999); pp. 50-58

[4] Pauwelussen, J.P.: The dynamic performance of narrow actively tilting vehicles. In: Proceedings of AVEC 2000, 5th Int'l Symposium on Advanced Vehicle Control, Ann Arbor, Michigan (2000); pp 569-576.

[5] www.maxmatic.com/ttw_index.htm

[6] autos.groups.yahoo.com/group/tilting/

[7] www.brinkdynamics.com

[8] www.carver.nl