The demands placed on suppliers in the automotive sector are changing dramatically. Increasingly, suppliers are being called upon to integrate components into complex systems – a development task that can only succeed on the basis of close partnerships with vehicle manufacturers. The future will bring continued demands for reduced fuel consumption, emissions, weight and installation space, along with enhanced comfort, safety, and driving dynamics. To meet these goals, innovative solutions and new products are essential.

ZF has taken responsibility here, demonstrating expertise in generating comprehensive solutions with its intelligent suspension systems. In doing so, it consistently pursues a systems approach in developing and manufacturing new products and technologies that represent real advances. ZF provides overall solutions that meet the demands of overall systems. One example: As a suspension specialist and manufacturer of electric drives, ZF can also implement the full range of strategies for ride-height control and electronic damping systems, and thus offer production-ready solutions today for the vehicles of tomorrow.

**BasicLine**

**Basic damping operations**
The BasicLine from ZF – this means clear standardization of twin-tube dampers and suspension struts. Its worldwide standardized development and production processes and its uniform product specifications deliver on the promise of basic damping operations. The BasicLine’s underlying principle is a modular system of components that ensure the optimum cost/performance level – demonstrated millions of times.

**Product solutions**

- BasicLine
  - Twin-tube damper with piston rod / piston Ø [mm]
    - 11/27 or 13/30
  - Suspension strut with piston rod / piston Ø [mm]
    - 20/30 or 22/32

**CustomizedLine**

**Individual customer demands and additional damping functions**
Based on a modular system, the CustomizedLine meets customer-specific wishes. The development work behind this line has produced stronger individualization and a greater focus on vehicle adaptation. In addition to monotube dampers, twin-tube dampers, and suspension struts, this product range also includes modules. The CustomizedLine also features additional damper functions that offer appreciable added value for vehicle makers and end consumers. The constant focus of these products is to combine superior driving comfort, safety, and dynamics.

**Product solutions and additional functions**

- CustomizedLine
  - Customer-Specific Dampers and Modules
  - New Pre-loaded Valve Technology
  - Vario = Stroke-Dependent Damping
  - Sensitive Damping Control = Amplitude Selective Damping
  - Nooma® = Leveling System
  - CDC® = Continuous Damping Control Dampers

**ActiveLine**

**Active suspension systems**
The ActiveLine covers all controllable damping systems. These systems communicate with the vehicle’s other safety systems; they continuously respond to current vehicle data and thus ensure that damping is adjusted to the actual driving situation. With its electronic damping systems, ZF sets new standards in safety, comfort, and driving dynamics.

For car makers, these systems not only offer new potential for networking within the vehicle but also reflect the vehicle’s value on the market.

**Product solutions and additional functions**

- ActiveLine
  - CDC® = Continuous Damping Control System Technology
  - Active Roll Stabilization

**EcoRide**

**Preserving the environment with lightweight design**
The EcoRide product range is part of the CustomizedLine and ActiveLine. It encompasses all the solutions that make an effective contribution to reducing damper weight. Examples include the use of hollow piston rods, aluminum tubes, and plastic components. The EcoRide product range also includes environmentally friendly production processes.

**Product solutions and additional functions**

- EcoRide
  - Lightweight Design with Steel, Aluminum, and Plastic
  - Production Processes That Preserve the Environment
Shock Absorbers

The task:
High demands are placed on vehicle damping systems. Shock absorbers have to minimize vibrations and post-oscillation in the vehicle body generated by uneven road surfaces. They also have to ensure that the wheels are in constant contact with the road. Both these tasks have a crucial impact on driving safety and comfort. While taut damping characteristics increase driving safety, comfort declines. The reverse also applies: Soft damping increases comfort but reduces safety. To achieve both optimum comfort and optimum safety, sophisticated technical solutions are required.

The technology:
In monotube dampers, the floating separating piston forms an absolutely leakproof separation between the oil and the gas. The damping valves for rebound and compression are located on the piston. The piston rod and seal are especially important components because the pressurized system must remain perfectly sealed under dynamic loads. The Viton seal is applied to the piston rod by means of mechanical pre-loading and high internal pressure. Both materials and geometry have been optimized to minimize friction. Twin-tube dampers require lower gas pressure levels; 6-8 bar are enough to ensure precision damping as well as low noise levels even at high compression speeds.

Damping force and characteristic curves

A shock absorber’s damping force generally depends on the piston speed. As the piston speed increases, so too does the damping force. The degree to which this takes place is defined by valves. The design, arrangement, and combination of valves allow all the desired and/or optimum damping characteristics (curves) to be attained for different applications. A damper’s characteristic curve can be shown as a force/speed (F-v) diagram. Shock absorbers from ZF can feature degressive or linear characteristic curves as well as combinations thereof.

Characteristic curve degressive

![Characteristic curve degressive](image)

Characteristic curve linear

![Characteristic curve linear](image)

The Monotube Principle
When the piston rod moves in (compression), the floating separating piston compresses the gas cushion by the amount of oil corresponding to the volume of the piston rod. When the piston rod retracts (rebound), the nitrogen gas pressure pushes back the separating piston. Vibrational damping in both directions takes place via the multistage piston valve.

The Twin-Tube Principle
When the piston rod moves in (compression), some of the oil flows from the lower operating chamber through the piston valve into the upper operating chamber. A quantity of oil corresponding to the volume of the piston rod is thereby pushed through the base valve into the compensation chamber. When the piston rod retracts (rebound), the piston valve takes over the damping function, while a quantity of oil corresponding to the volume of the piston rod flows back through the base valve.

Suspension Strut Principle
The structure of the suspension strut corresponds to that of the twin-tube damper. In addition to damping, it also takes care of wheel positioning together with the track control arms, and thus ensures that steering movements are transmitted to or implemented by the wheels. It also absorbs the support spring forces via the spring seat, and supports lateral forces that arise especially when braking, accelerating, and taking curves.

Given these forces as well as the demand for minimal weight, the suspension struts are optimally adapted to individual vehicle models. In order to reduce friction, the bearing surfaces of the piston rod guide and the damper pistons feature special elements such as slide bushings as well as PTFE sheeting and coatings. ZF provides the best solutions for all classes of vehicles.
The technology:
ZF is a leader in the development and production of damper and suspension strut modules. High demands are placed on these modules: They have to ensure that vehicles run safely, comfortably, and quietly. Individual components have to meet high functional requirements, yet at the same time show a reduction in weight. Development, production, installation, and logistics from ZF fulfill the highest demands for cost-effectiveness and efficiency while also meeting uncompromising global quality standards. One example is the suspension strut module with wheel control, which consists of many individual components. Flawless interplay between the constituent parts is of paramount importance for the system’s operation and life span. The interaction between the individual components and rubber-to-metal parts, supporting springs, axial bearings, and dampers is a decisive factor in making sure that chassis systems (steering, braking, damping) operate smoothly. Damper and suspension strut modules are used on the front and rear axles of passenger cars from compacts to luxury sedans.

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**Customer-Specific Dampers and Modules**

**Suspension Strut Module**

- Mounting cap (thread-in cap)
- Flexible gaiter
- Sound insulation/Tolerance equalization
- Mounting support
- Axial bearing and upper spring seat
- Compression stop buffer
- Support bearing
- Spring washer (zinc/rubber)

**Improved comfort and steering performance**
- Lower undesired lateral forces
- Optimization of load distribution in the spring seat
- Minimal friction in suspension strut and mounts

**Greater driving comfort**
- Multi-directional support bearing
- Support bearings feature different longitudinal and lateral degrees of stiffness
- Rubber-to-metal part design (ring eye rubber joints and support bearings) optimized to reduce secondary stiffness

**Reduced tolerances**
- Smaller ride-height differences
- Reproducible, low system friction

**Optimized design of support bearing properties**
- Lower noise levels
- Precise damping even for the smallest, high-frequency axle movements
- Any installation position thanks to separation of oil and gas
- No oil foaming
- Low weight
- Variable linear and degressive characteristic curves

**Lower weight**
- Components optimized by FE analysis
- Targeted material selection

---

**Monotube Damper**

- Piston rod
- Sealing system for piston rod
- Coated guide bushing
- Floating separating piston
- Gas pressure for supporting compression/damping forces

**Benefits**
- Lower noise levels
- Precise damping even for the smallest, high-frequency axle movements
- Any installation position thanks to separation of oil and gas
- No oil foaming
- Low weight
- Variable linear and degressive characteristic curves

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**Twin-Tube Damper**

- Piston rod
- Seal and guide unit
- Working piston
- Oil compensation chamber
- Working piston and piston valve
- Base valve

**Benefits**
- Low friction
- Greater ride comfort
- Variable curve configuration thanks to multi-stage piston and base valves
- Short installation lengths
New Pre-Loaded Valve Technology

The technology:
The new pre-loaded valve technology is the result of consistently further developing the standard valves while incorporating expertise from monotube dampers. Using the latest research and development methods, including fluid analysis, a completely new piston generation has been developed which not only increases driving comfort but also ensures excellent damping of vibrations in the vehicle body. Very rapid opening and closing processes in the valve ensure outstanding wheel damping, which in turn enables safer driving action. In addition, innovative piston geometries further optimize the damper’s noise emissions. This brings a clear increase in driving comfort.

Benefits
- Greater driving safety and comfort
- Reduced NVH
- Longer service life
- Variable adjustment to meet customer needs (sport vs. comfort)

Vario Damper

The technology:
Vario dampers are available in monotube or twin-tube design. Control grooves in the cylinder tube create a hydraulic bypass which enables stroke-dependent damping. Mechanically formed in the cylinder tube of the shock absorber, the hydraulic bypass affects the piston valve. The piston travels over the bypass groove depending on the damper position and stroke. When oil flows over the groove, hydraulic resistance is reduced and therefore the damping force as well. Vario technology is used in vehicles that have to carry a wide range of different loads, yet still meet the highest comfort and safety standards.

Stroke-dependent damping from ZF

When the piston travels over the bypass groove, driving comfort is enhanced. Outside the groove range, damping forces are considerably greater – which means a plus for driving safety. Careful design of the transition profile between the groove and the smooth part of the cylinder prevents abrupt changes in damping forces.

Benefits
- Enhanced comfort
- Economical
- Can be integrated in standard dampers
- No control elements needed
- Can replace existing dampers
Sensitive Damping Control

The technology:
Sensitive Damping Control represents a further evolutionary development of today’s dampers. It stands for a combination of agile and comfortable driving. Sensitive Damping Control is a self-contained damping system that greatly reduces the target conflict of axle/body damping, without having to provide the entire functional range of an electronic system. ZF’s solution is based on distributing the damper characteristics over two valves. A second valve on the piston rod is suspended between springs, which allow for a certain play depending on the vehicle model. While the standard valve handles small excitations, damping forces from both valves are available for larger disturbances.

Sensitive Damping Control is a way to enhance driving comfort without any loss in driving safety. It is used in passenger cars from compacts to upper mid-sized vehicles. There is still room for comfort to be heightened in this sector without risking safety. For minor excitations, body vibrations in sports-oriented vehicles can also be dampened without any loss in comfort. Commercial vehicles represent yet another area of application. Sensitive Damping Control is also effective in enhancing comfort in light commercial vehicles (LCV).

Benefits
- Optimum road contact
- Greater comfort with no loss in safety
- Improved insulation of vehicle body against high-frequency road-based excitation
- Compensates for loss in comfort for run-flat and low-profile tires
- No electronic control system

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Comparison of Sensitive Damping Control vs. standard dampers

For strong excitations from the road surface, the second valve increases the damping force, which exceeds the properties of a standard damper and makes a significant contribution to driving safety. When damper excitation is low, driving comfort is increased.
Nivomat® – Always at the Right Height

The task:
Constant heavy or changing loads, as well as trailer dynamics, place high demands on both vehicle and driver. Extra weight on the rear axle shifts the center of gravity, and exerts a major impact on driving performance in the process. In critical situations, the vehicle can be very difficult to control, while inconsistent responsiveness makes driving comfort nearly impossible. Other consequences can be expensive. Fuel consumption rises, and tire wear increases due to uneven power transmission. Greater strain is also placed on the axle as a whole. The Nivomat®, the leveling system from ZF, counters the negative effects of loads. There are many vehicle applications, especially in mid-sized classes, such as station wagons, vans, SUVs and sedans that offer the Nivomat® as an option. The Nivomat® is available as a damper, spring damper, suspension strut, or suspension strut module.

The technology:
The Nivomat® is installed on the rear axle in place of a conventional damper. Fully automatically and without additional electronic systems, this compact device pumps the vehicle up to its optimum ride height after only a few meters. The Nivomat® takes the energy needed to do so from the relative movements of the wheel and vehicle body. For every load condition, this maintenance-free system sets the ideal vehicle height, thus ensuring a safe and comfortable drive.

Benefits
- Greater safety
  - Safe handling thanks to constant vehicle height for all load conditions
  - Constant axle height makes driving on bumpy surfaces safer
- Better comfort
  - Responsiveness doesn’t become fuzzy under high axle loads
  - Less driver fatigue
- More economical
  - Less wear on tires and axle
  - Lower fuel consumption due to better aerodynamics
- Reliable
  - No additional on-board electronics; eliminates possibility of system failures
- Environmentally friendly
  - No additional energy required for pump operations
  - No additional CO2 emissions

Nivomat®: Clear advantages for all load situations

1. Transporting passengers
2. Transporting goods (sample products, tools)
3. Special vehicles (police, ambulance, fire department, roadside assistance, service technicians)
4. Family trips (major load shifts, such as with roof racks)
5. Goods
6. Motor homes
7. Horses
8. Boats

Stabilizes couplings for all trailers
The task:
Over recent decades, electronic systems have substantially enhanced the operation of vehicle mechanical functions – and the field of damping technology is no exception. Development work on the next generation of vehicles is focusing to an ever greater degree on active and semiactive damping and suspension systems. With its electronically controlled damping systems, ZF is setting new standards in driving safety, comfort, and dynamics. One of the strengths at ZF is that it supplies not only components but also entire systems including both hardware and software. ZF is also a leading module supplier of active chassis systems such as roll stabilization and spring mount adjustment. Many of the major vehicle manufacturers rely on the systems expertise of ZF for their high-end products. Today’s mid-sized and highend vehicles feature a number of active electronically controlled systems that have thus far operated largely independently of each other. In order to further resolve the compromise between driving safety, comfort, and dynamics, the automotive industry is increasingly seeking to integrate individual systems. ZF is superbly prepared for this development and will play an active role in shaping it.

**Active Suspension Systems**

**CDC® – Continuous Damping Control**

The technology:

CDC® is an electronic damping system that noticeably increases driving safety, comfort, and dynamics by adjusting damping forces optimally for each individual wheel. A control unit calculates the requisite damping forces within milliseconds, and adjusts the dampers just as quickly. Vehicle sensors monitor values such as body, wheel, and lateral acceleration, and use them to generate the ideal damping forces for each individual wheel on a continuous basis. The CustomizedLine includes the CDC® actuators; the ActiveLine goes beyond the actuators to offer the entire system consisting of actuators, sensors, hardware, and software.

**Benefits**
- Greater safety thanks to optimized wheel damping
- Enhanced driving comfort and dynamics
- Reduced roll, pitch, and vertical motion
- Shorter braking distances thanks to better road contact
- Continuous adjustment in real time

**Variable Damping**

Optimum comfort, superior safety

This graph of characteristic curves shows the range in which CDC® can continuously vary damping forces in compression and rebound.

The core of the CDC® damping system is the proportional valve. Depending on its position, the opening for oil flow is expanded (soft damping) or constricted (firm damping).
Benefits
- Damping forces are only increased in the direction of motion where they are needed
- Damping forces are adjusted with targeted precision
- Optimum wheel damping
- More degrees of freedom in vehicle tuning
- Integrated fail-safe strategy

CDC® Overview: Skyhook Control Strategy (Software)

The technology:
Damping forces for each wheel are individually controlled for the directional movements of wheel and body. Thus they always provide the best possible compensation for vehicle body movement relative to a stationary center position. The skyhook principle keeps the vehicle body as stable as possible, independent of driving and road conditions. The control strategy seeks to calm vehicle body movement, as if the moving vehicle were connected to a hook fixed on the sky. As a result, the body moves along like a sedan chair parallel to the sky – as if were “hanging from the heavens”.

Comparison of CDC® Advanced Skyhook control strategy vs. conventional dampers

<table>
<thead>
<tr>
<th>Feature</th>
<th>Conventional</th>
<th>ZF Advanced Skyhook</th>
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</thead>
<tbody>
<tr>
<td>Elevation</td>
<td>0</td>
<td>+++</td>
</tr>
<tr>
<td>Stability</td>
<td>0</td>
<td>+++</td>
</tr>
<tr>
<td>Comfort</td>
<td>0</td>
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<tr>
<td>Traction</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td>Handling</td>
<td>0</td>
<td>+++</td>
</tr>
</tbody>
</table>

A comparison with passive dampers clearly shows the advantages of CDC® with a Advanced Skyhook control strategy. Considerable advantages result for each of the dimensions shown.
CDC\(^4\) – The System for Both Axles

The technology:
For passenger cars from the lower mid-sized to sports car segments, a CDC\(^4\) system is used that has one CDC\(^4\) damper on each wheel point. Data from sensors and other vehicle systems such as ABS are processed by the ECU, and the results are transferred to the CDC\(^4\) dampers. The result: A marked increase in driving safety and comfort.

New in the CDC4: The body acceleration sensors are no longer needed. The ECU takes over their tasks without any restriction in system performance.

CDC\(^{1XL}\) – The System for Rear Axles

The technology:
Developed specially for compact cars and vans, the CDC\(^{1XL}\) system intervenes at the spot where comfort and safety can be influenced the most in these vehicles – on the rear axle. For here is where passenger and luggage loads have the greatest effect.

Tuning for conventional dampers previously had to address the conflicting aims of driving safety and comfort and address the question: What should the suspension be tuned for?

Maximum safety for a full load with five people plus luggage? Or perhaps greater comfort for just the driver and luggage? Because safety is the greatest maxim, compromises are always made at the cost of comfort.

The newly developed CDC 1XL eliminates this compromise because its rear-axle dampers are not passive but rather electronically controlled. Together with an ECU which also has integrated sensors, it provides a marked increase in driving safety and comfort.
Active Roll Stabilization

The technology:
Active hydraulic roll stabilizers from ZF enable dynamic driving while increasing both safety and comfort. These units generate stabilizing forces on the front and rear axles to minimize or completely eliminate roll movements in the vehicle body during curves. They enable optimal turn-in and load alteration performance. When the vehicle is moving straight ahead, the electronic control unit adjusts the damping level to ensure softer, more comfortable suspension properties. Copy movement in the vehicle body is reduced, which gives the vehicle greater agility and cornering predictability throughout the entire speed range.

Active roll stabilization systems are used in mid-sized and high-end vehicles.

Benefits
- Minimizes roll movement
- Improves turn-in and load alteration performance
- Decouples wheel movement in straight-ahead driving

Greater Safety Reserves with Integrated Suspension Systems

Regardless of the category of cars, one of the most important objectives for car manufacturers continues to be vehicle safety when driving. As the leader in the field of chassis technology, ZF will be one of the driving forces behind these developments in the future too.

Integration is the name of the game
The main aspect of this safety systems trend continues to be the electronics. This is because integrating the sensor systems, control software, and control technology of the individual units into a system that works together can result in critical driving situations being identified and corrected much quicker than can be expected of the driver. There is increasing demand for innovative, electronically controlled by-wire technologies to be networked and integrated into vehicles. Therefore in the event of a critical situation, the unit that can address the issue most effectively is the first to respond. With IWD (Intelligent Wheel Dynamics), the ZF transmission, damper, and steering units work together with other auxiliary electronic parts to improve vehicle safety.

Safety at all times
But ZF’s safety products don’t just kick in when a crisis occurs – they operate to improve your driving at all times. For example, it doesn’t take a risky swerving maneuver for IWD to improve a vehicle’s steering – it is also activated when taking fast corners on a normal drive. The electronically controlled CDC® and ARS® prevent a vehicle from rocking during load changes, making for a smoother ride for the driver and passengers alike, both in normal driving circumstances and in dicier situations.

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Preserving the Environment with Lightweight Design

A major challenge in chassis technology is the search for new ways to make individual components even lighter while continuing to meet the ever more sophisticated demands of the market. Lightweight design for the automotive industry strives to meet the sometimes conflicting demands for greater safety and comfort, lower fuel consumption, and high recyclability.

Cost-effectiveness:
There are various mutually combinable “intelligent lightweight design” strategies to reduce damper weight. One way is to use lighter or alternative materials, such as plastic, aluminum, magnesium or high-strength steel. Another option is to use finite element methods to optimize dimensions and component design. Thanks to expert utilization of the latest methods and processes, such as cold-pressing lightweight components, ZF is a specialist in large-scale series production and strategic development projects such as the 1-liter car. Lightweight design is one of the core areas of expertise at ZF.

Intelligent lightweight design utilizes the weight-saving potential in outer tubes, spring seats, cylinder tubes, piston rods, stabilizer mounts, top eye and brackets. It can reduce vehicle weight by as much as four kilograms, at only moderate additional cost.

The EcoRide product range also features environmentally friendly processes. One example is the elimination of energy-intensive procedures such as welding. Some of the environmentally harmful paint work can also be eliminated. Although the technologies used for this range are cutting-edge, customers can be sure of the products’ reliability for it is verified in both theory and practice.

Methods and Tools:
Before the product is created, an innovation process takes place in which new ideas are generated and evaluated. To develop the strategies and products needed to ensure mobility now and in the future, and to be a reliable partner for our customers in the automotive industry worldwide, ZF invests continuously in design, simulation, testing, and configuration of suspension systems. Project management systems at ZF ensure optimum development times. Cutting-edge development tools ensure the quality of development results in the product range EcoRide.