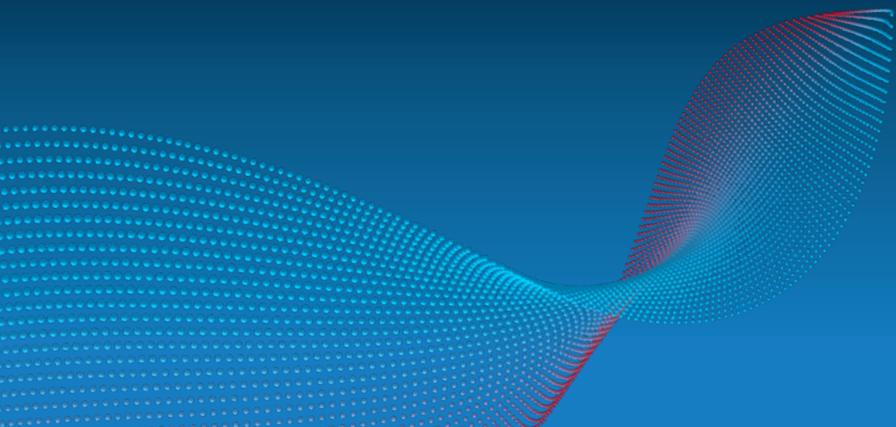




Performance: Damping Technology by ZF



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Chassis Technology That Moves: ZF Damping Technology

The automotive industry is facing enormous challenges: Electric mobility, autonomous driving and digitalization have already begun to change traffic more than any other development before.

ZF is ideally equipped for this change: With its core competencies in electric driveline solutions, Vehicle Motion Control, Integrated Safety and Autonomous Driving, the company is making it possible to experience technologies of the future today. Because one thing is certain: As long as a vehicle has wheels, it will need a chassis; and only few chassis components are as crucial for dynamic handling, safety and comfort as the damping system. For decades, automotive manufacturers have relied on ZF and its extensive portfolio, which ranges from proven conventional components to complete, actively controlled and networked systems.

Technological expertise worldwide

This expertise is valuable because people's desire for mobility remains unbroken worldwide. Whether in America, Europe or in the important growth markets of China or India: People everywhere have to get to work, goods need to arrive at their destinations, children have to get to school, or people simply want to enjoy the ride. Without being aware of it, they always rely on a pleasant ride and thus on damping technology.

Damping "irons out" bumps in the road, keeps the wheels on the road surface even when cornering, prevents unwanted inertia from coming into play in stop-and-go urban traffic and much more. Additional requirements in terms of comfort, safety and dynamic handling arise depending on the segment, market and customer. Whether the car is driving autonomously or being steered by humans will also matter in the future. ZF can fulfill all these wishes because the company supports automotive manufacturers in customizing the damping to the respective model or sales region. The Group ensures that the optimal solution is achieved for the desired application already in the development stage.

ZF works closely with vehicle manufacturers during each step of the way – from concept to start of production, from the test bench to the test track or even the racing circuit. Since the company is also represented on every continent with plants as well as development and service locations, vehicle manufacturers worldwide can rely on ZF's expertise.



RIDE & HANDLING



Damping significantly contributes to achieving the optimum combination of comfortable and sporty driving.

REBOUND & COMPRESSION STOP



Speed bumps, large potholes and other obstacles can lead to an uncomfortable stopping point in the stroke limit of the chassis. These effects are mitigated by shock absorbers that also limit the force introduced into the vehicle body.

AUTONOMOUS DRIVING



Autonomous driving is no longer a vision of the future – even today, cars can cover certain routes independently. This leads to new and higher demands on the chassis in terms of comfort and also poses a challenge for the damping technology.

LOW NOISE



When a car is on the road, the chassis generates vibrations that can radiate into the passenger compartment, resulting in noises that can be bothersome to occupants. ZF therefore develops its damping systems in such a way that the interior acoustics are optimized.

IMPACT DAMPING



Small potholes and other bumps in the road considerably reduce the comfort of the occupants and make it more difficult to control the vehicle. Using special technology, damping can compensate for these effects.

MOTORCYCLE



Motorcycles promise pure enjoyment, whether you are out on a fast and challenging tour or a more relaxed excursion, alone or with a passenger. All of this demands a lot from the chassis, because neither dynamics nor stability should be sacrificed.

Prepared for Every Eventuality

Automotive manufacturers may not have any influence on what the route looks like between start and finish – but they do have an effect on how it is perceived by the vehicle occupants. Whether for sporty cornering or for taking long journeys in comfort: ZF develops its shock absorbers in such a way that even entry-level products cover a multitude of possible applications. Depending on the type and final design, a wide variety of advantages come into play. Further add-on modules and advanced complete systems ensure that the passengers enjoy every trip.

What the Damping System has to Master

Innovation with tradition: ZF has been active in the damping business since 1934. Throughout its history, the Group has met new challenges with its products again and again.

Today, the industry is once again facing major upheaval. In addition to new laws regarding safety and emissions, automotive manufacturers and their customers are demanding more in terms of comfort and driving pleasure. This leads to industry-wide trends, among others electric mobility and electrified drives, integrated safety and highly automated and autonomous driving functions. These trends are also changing the tasks that a damping system has to perform.



Safety

The era of isolated individual systems in the vehicle is drawing to a close. Fully integrated and networked systems will replace the current status quo, allowing the shock absorber to help prevent accidents, or at least to limit their consequences, even in difficult driving situations.

ZF is also supporting vehicle manufacturers in protecting road users who are most at risk: Over time, vehicle body fronts are designed lower and lower so that pedestrians suffer less injury in the event of a collision. This changes the installation positions of the suspension struts and shock absorbers, so that these components now have to deal with very high transverse forces.

ZF therefore designs its shock absorbers to be exceptionally rugged even in their basic version, enabling them to reliably absorb such forces.



Comfort

It's something every passenger is aware of: If you're not paying attention in traffic, every bump in the road is much more noticeable. That's more than just annoying – some people even get motion sick from it. In the coming era of highly automated and autonomous driving, this problem will become more acute, as even the driver's seat is increasingly being transformed into a passenger seat. Semi-active and active damping systems, such as those already offered by ZF, have the advantage here: They can decouple the passenger compartment from unpleasant motions to the greatest extent possible, making the experience more and more like a ride on a "flying carpet." But even during normal driving, they enhance the driving experience by providing the driver with important feedback on road conditions without being uncomfortable.



Environmental protection

Climate targets, fuel consumption standards and the threat of a driving ban for diesel vehicles:



Manufacturers who want to overcome these challenges often turn towards electric mobility. However, an electric motor produces far less noise than a conventional drive. Up to now, the combustion engine drowned out other noises that entered the passenger compartment through the chassis. ZF is therefore developing its shock absorbers in collaboration with the customer to ensure that occupants will not notice any noise that might occur. Depending on the application, the Group minimizes many of these noises down to the physical limit of acoustics.

However, shock absorbers can also help to reduce emissions from gasoline and diesel engines through intelligent lightweight design – one of ZF's core competencies. The combination of lightweight and alternative materials such as plastic, aluminum or high-strength steel with precisely fitting piston sizes can save up to four kilograms of weight per vehicle. This is reflected in lower fuel consumption and reduced exhaust emissions.

Continuous Damping Control: Optimum Damping for Every Wheel on any Road



Continuous Damping Control (CDC) has been a popular mainstay in the ZF portfolio, thanks to the ability to switch to optimum damping within a fraction of a second or the option to switch between sport-tuned firm and luxuriously soft damping with the push of button. CDC can stabilize vehicle superstructures independently of road conditions using the “skyhook” principle.

On long journeys and on poorly maintained roads, CDC reduces strain on the spine and thus is gentle on passengers’ backs, benefiting commuters as well as others. ZF has also set its sights on the future, because in the coming age of autonomous driving, the comfort demands on the part of occupants will rise to a level for which CDC is already equipped.

Want handling that is more dynamic? CDC makes it possible by influencing the wheel load fluctuations of the car, thus ensuring perfect traction at all times. For example, this allows the vehicle to accelerate dynamically or steer when cornering without impairing tracking behavior or stability. And in the worst-case scenario, such as emergency braking, this feature ensures greater safety on the road.

The technology explained

The semi-active damping system, which has proven itself millions of times over, constantly uses its sensor architecture to collect data on the condition of the road, the vehicle speed and driver actions and transmits it to a central control

unit. A solenoid-controlled valve provides each individual wheel with the ideal damping force for the current situation. Because CDC can switch so smoothly and quickly, it can optimally cope with many challenges – and is able to do so in all vehicle segments, from compact cars to luxury sedans. CDC also guarantees a good ride on motorcycles, be it while racing through curvy switchbacks or on an adventure tour.

Add-on feature CDCrci

Even finer tuning of the shock absorber characteristics can be achieved with the CDCrci feature, which electronically regulates the damping forces independently in the rebound and compression direction. CDCrci thus meets the increased requirements for controlled compression damping on rough roads and enables further advantages in terms of driving dynamics and comfort, especially for SUVs.

Power Perfectly Metered: Selective Damping Control 3

For many, driving a car is an emotional experience. The phrase “need for speed” exists for a reason, but those who have pursued it could expect at the very least their passengers complaining about damping that was too hard – if it wasn’t the driver’s own back that might be aching from it.



The frequency-selective technology SDC3 (Selective Damping Control) now allows vehicle manufacturers to find a good compromise between comfort and precise handling with sporty dynamics on the cost-efficient basis of conventional damping technology. SDC3 exhibits its advantages especially when installed in vehicles with large rims or low-profile tires, such as sport, truck or crossover models.

The technology explained

The heart of SDC3 is a frequency-dependent valve module that divides the damping force characteristics in the rebound direction into high- and low-frequency damping forces. In the case of low-frequency excitations – high cornering forces which occur during evasive maneuvers on the highway or when cornering on a country road – stabilizing, high damping forces are generated. The car is easier to steer, which increases safety. In case of high-frequency vibrations – small, rapidly occurring road unevenness from sources such as cobblestones, rough asphalt or tar patches – SDC3 operates on a low damping force level. The passengers remain isolated from the vibrations, which leads to a noticeable increase in comfort.



It's all About Modularity

Compact city cars, minivans, sports sedans, off-road vehicles: Successful vehicle manufacturers offer a wide variety of possible model ranges to reach different customers.

The driving experience should be as varied as the intended uses – because this experience is just as much a part of the brand core as design, engine sound and reliability.

As an integral part of the chassis, damping represents the link between road, car and driver. And because every car is different and has different challenges to master, this also needs to be reflected in the damping characteristics. Manufacturers therefore rightly want a more or less tailor-made solution for each individual model range – and often for different engines or regions as well.

ZF fulfills this wish with an economical and scalable modular system that allows conventional, semi-active and active shock absorber technology to be precisely optimized for every application and budget.

Start right with the basics

ZF shock absorbers have been the proven standard in damping technology since the 1930s. Every product that the Group develops for its customers is based on monotube or twintube dampers. Even in their entry version, ZF twintube dampers are economical for the vehicle manufacturer as well as resilient and space-saving thanks to their short installation length. In addition, monotube dampers feature improved noise characteristics and are optimized for lightweight design. In this way they contribute

to reducing emissions or, in the case of electric vehicles, increasing the range. The monotube damper thus closes the gap between standard and electronically controlled chassis with an attractive price/performance ratio.

Five by five

Based on mono- or twintube dampers, five further factors are crucial for ZF's modularity principle:

- The size of the shock absorber, including suitable rebound and compression stop technology
- Various valve systems for optimum characteristic curve attributes
- Optional material mix in container design
- Control algorithms and electronics for semi-active and active damping
- Construction kit for actuators with semi-active and active damping

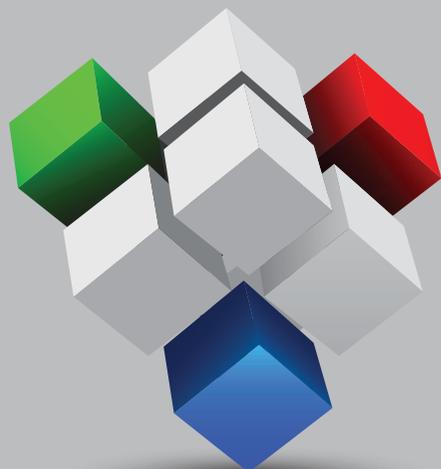
Spotlight on additional modules: Rebound and compression stops

Additional damping force is generated by rebound and compression stops, depending on the stroke, which in turn limits the stop forces acting on the axle – and thus on the vehicle body. It is therefore vital that the rebound and compression stops are individually adjusted to the respective vehicle model. This is associated in particular with additional comfort for passengers.

Vehicle manufacturers can also use it to limit the forces introduced into the vehicle body by the chassis. Weight and costs are reduced because no additional compensating components have to be installed.

Custom-made in volume production

ZF attaches great importance to developing the optimum shock absorbers for every vehicle. ZF shock absorbers are highly customizable in terms of size, additional features, algorithms and actuators and can therefore be adapted to every vehicle type and application. In addition, there are various lightweight design options based on material mix and thickness, such as hybrid spring plates made of a steel-and-plastic composite. With semi-active and active damping technology, ZF can not only supply the hardware but also offers the appropriate electronics and control software from a single source. ZF engineers accompany and support the OEM in a thorough customization process – including several weeks on the test track – to ensure that the shock absorber is perfect for the respective vehicle model.



Smooth as can be: Active Damping Concept sMOTION

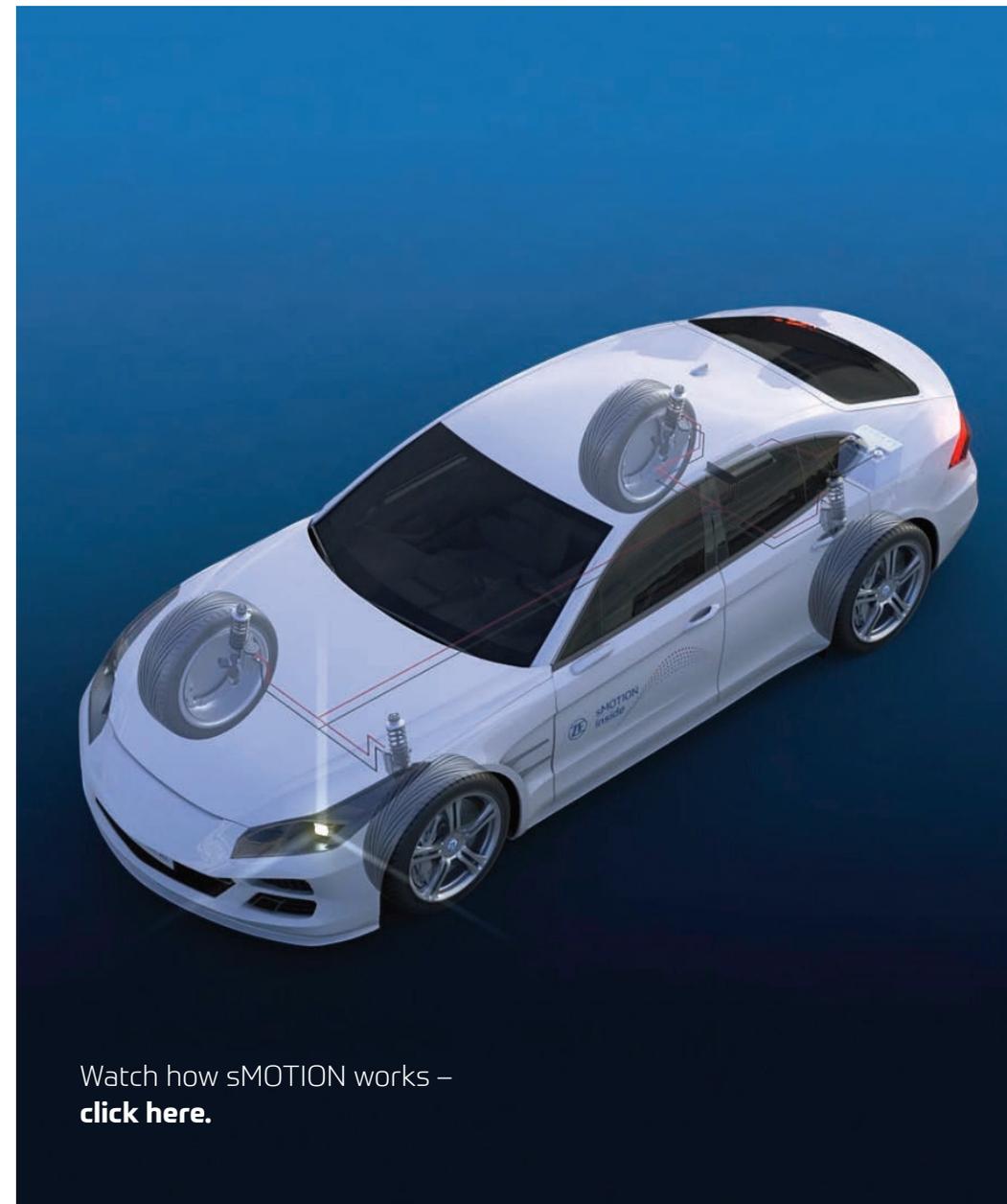
What if a shock absorber no longer depended on external influences to fully deploy its damping power?

What if it were able to take action itself – instead of just reacting, as has been the case so far? With the active damping concept sMOTION, ZF promises a groundbreaking new level of

comfort, safety and dynamic handling. Thanks to sMOTION, vehicle occupants get a feeling of unshakable calm as they float over uneven surfaces of all kinds.

The technology explained

Each wheel is fitted with an actuator that can actively pull the wheel upwards or push it downwards. It almost completely eliminates car body vibrations that might be unpleasant for the driver and passengers. It doesn't matter whether the vehicle is exposed to immense lateral forces when cornering fast, generating pitching movements when accelerating or braking, or driving over bumps, humps, rough asphalt, gravel or the like: sMOTION effectively smoothes over any unwanted, bothersome movement.



Overview: ZF Damping Technology

RIDE & HANDLING



- Conventional: SDC2/SDC3
- Semi-active: CDC/CDCrci
- Active: sMOTION

LOW NOISE



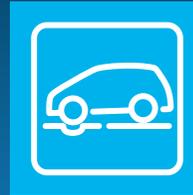
- Various valve technologies
- Designed as required

REBOUND & COMPRESSION STOP



- Conventional: HRS/HCS
- Semi-active: CDCrci
- Active: sMOTION

IMPACT DAMPING



- Conventional: SID
- Semi-active: CDCrci
- Active: sMOTION

AUTONOMOUS DRIVING



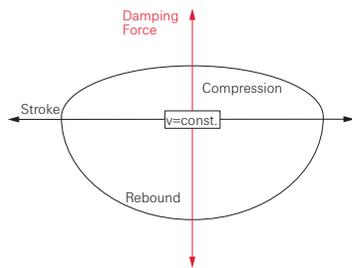
- Conventional: SDC3
- Semi-active: CDC/CDCrci + preview
- Active: sMOTION + preview

MOTORCYCLE

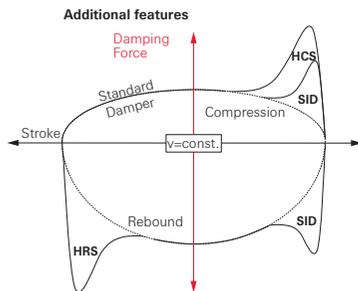


- Conventional shock absorbers
- Semi-active: CDC

STANDARD DAMPING

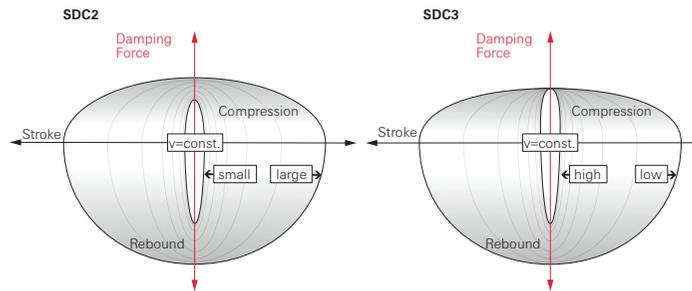


END-POSITION DAMPING



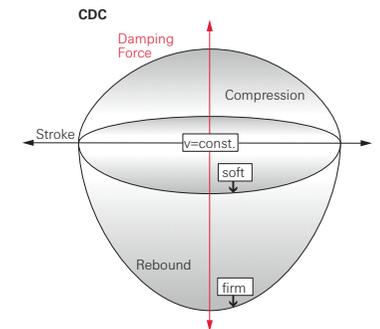
- HRS** – Hydraulic Rebound Stop
- HCS** – Hydraulic Compression Stop
- SID** – Sensitive Impact Damping

AMPLITUDE- AND FREQUENCY-DEPENDENT DAMPING



- SDC2** – Sensitive Damping Control Amplitude selective Damping
- SDC3** – Sensitive Damping Control Frequency selective Damping

SEMI-ACTIVE AND ACTIVE SYSTEMS



- CDC** – Continuous Damping Control
- sMOTION** – Active Suspension

A Systematic Approach to the Future

Modern problems require modern solutions. As more people strive for mobility, traffic is becoming increasingly complex worldwide.

Drivers and passengers have requirements for their cars that differ greatly. Sporty drivers want to test the limits, while families focus on safety, which is why companies are constantly developing new assistance systems. And of course, comfort should not be neglected.

In order to meet such demands, it is no longer sufficient for each component to simply function well on its own. Their full potential can only be tapped if the individual components, along with subsystems and parallel systems, are intelligently and efficiently networked with each other. The prerequisite here is system solutions and integration, and ZF can meet this need from a single source like no other technology supplier.

see. think. act.

This is due to ZF's comprehensive portfolio in the four technology fields of Vehicle Motion Control, Integrated Safety, Electric Mobility and Automated Driving, which is the only way it is possible to keep track of a complex control network that opens up new market opportunities. In this way, ZF can supply complete systems that precisely meet the requirements of manufacturers and end customers.

ZF summarizes the causal chain of these technologies in the slogan "see. think. act." An example of this is the sensor set – consisting of radar, LIDAR and camera – detecting a potential collision, with the data being processed by the vehicle's control box, which estimates whether it is still possible to prevent the accident through evasive maneuvers or by braking. In any case, the car activates its braking system, the seat belts tighten, and the power-assisted steering is activated. If semi-active or active shock absorbers such as CDC or sMOTION are fitted, they can already adjust the damping force required to increase the traction of the wheels, making it easier to carry out evasive maneuvers while also shortening the stopping distance. In this way it is still possible to avert the accident. By the way, sensors can now also recognize what kind of danger is imminent. That's important, because whether it is another car, a pole, or even a pedestrian plays an important role in the choice of damping force.

Predictive damping

However, it is not necessary for the worst-case scenario to occur before action is taken. Intelligent damping through the use of constant communication with vehicle sensors offers



a variety of advantages in terms of comfort. Up until now, shock absorbers have only been able to respond to inputs and forces after they have already come into contact with them. What if the sensors were able to tell the damping system that road bumps or bends were approaching? The damping force would not only proactively compensate for the road condition but also be able to align the characteristic curve with the current driving style, with more feedback in sport mode and complete decoupling from asphalt conditions during autonomous driving. Further opportunities arise from networking, for instance through car-to-car

or car-to-cloud communication. This would allow the cars in front to warn those behind them of uneven surfaces or other obstacles. Such "remote damping" is no longer some distant vision of the future. Damping technologies such as CDC or sMOTION are already prepared to do this. Development projects at ZF are currently testing the necessary interaction of sensors, signal processing and regulation algorithms. In any case, it will become clear that damping will continue to be a crucial component of the mobility of the future as an indispensable interface between the road, chassis and driver.

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ABOUT ZF

ZF is a global technology company and supplies systems for passenger cars, commercial vehicles and industrial technology, enabling the next generation of mobility. With its comprehensive technology portfolio, the company offers integrated solutions for established vehicle manufacturers, mobility providers and start-up companies in the fields of transportation and mobility. ZF continually enhances its systems in the

areas of digital connectivity and automation in order to allow vehicles to see, think and act.

ZF has a global workforce of some 149,000 employees at 230 locations in 40 countries. In 2018, ZF achieved sales of €36.9 billion. ZF invests over six percent of its sales in research and development annually.



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