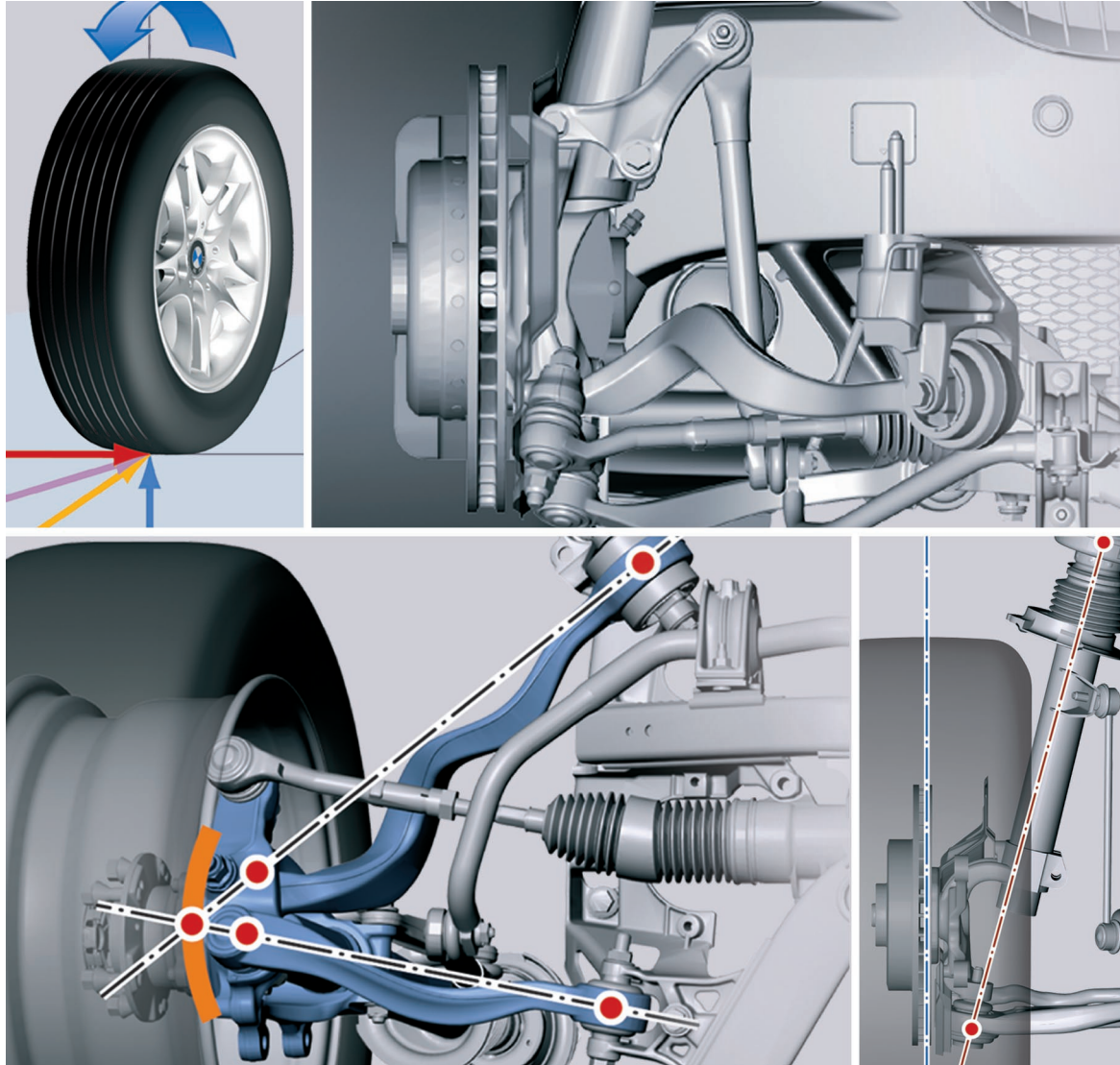


Participant 's Manual

Basic principles Chassis



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VS-12 Aftersales Training**

Participant's Manual

Basic principles Chassis

Definitions of terms

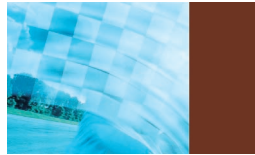
Relationships between axle geometry parameters

Axle kinematics

Faults and their effects

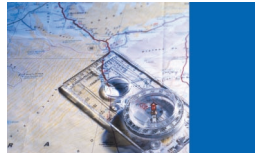


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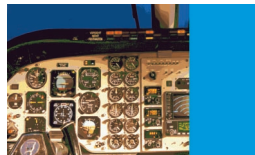


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Development of axle geometry

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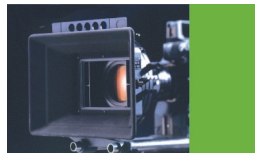


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Goals

Basic principles Chassis

Benefits to the reader

To get the most out of this document you need to have some prior knowledge of axle geometry. This prior knowledge can be acquired with the SIP and "Basic principles Chassis" training course. This brochure is designed as an accompanying document to the seminar.

Using the contents described in this document you will be able to complete your knowledge of the basics of axle geometry. It will enable you to name and locate the various angles relating to axle geometry. You will also have an understanding of how the various axle geometry parameters interact. Using the knowledge acquired from the contents of this course, you will be able to carry out work on modern BMW chassis properly.



Introduction

Basic principles Chassis

Development of axle geometry

History

Even the very first wagons that man used to carry his loads had to be steerable. This was easy to achieve with the first single axle vehicles which were pulled by men or animals. Later on, however, with the advent of motorization, it became necessary to attach wheels in a way that allowed them to rotate and swivel, thereby steering the vehicle. Since the beginning of vehicle construction, this has been one of the basic design tasks. Development has ranged far and wide, from simple carriage steering which was usually a pivot axle design, right through to the steering systems used today. The breakthrough for a four-wheel vehicle steered via the front axle came with the patent for the Ackermann/Lankensperger king-pin steering system (1818). This type of steering could not gain acceptance in carriage construction. It only came into more widespread use with the advent of the technically more challenging automobile at the beginning of the 19th century. The reason for this is that this steering design required a great deal more design effort than, for example, the pivoted bogie steering which was in widespread use at that time. The development of the king-pin steering system made it possible to turn the steered wheels at different angles. This meant that, when cornering, the extensions of the wheel axes met at the centre point of the curve. This ensured that the wheels turned correctly, from a point of view of geometry.



1 - Even this BMW features all the relevant axle geometry parameters.

This form of steering system featured the main geometric parameters which are still relevant for modern steering systems. These are the chassis-specific terms which

will be examined in this participant's manual. These include, for example:

- Wheelbase
- Track width
- Track
- Camber
- Spread
- Caster
- Steering roll radius
- Toe-differential angle



TF03-4263

2 - The chassis of a modern BMW

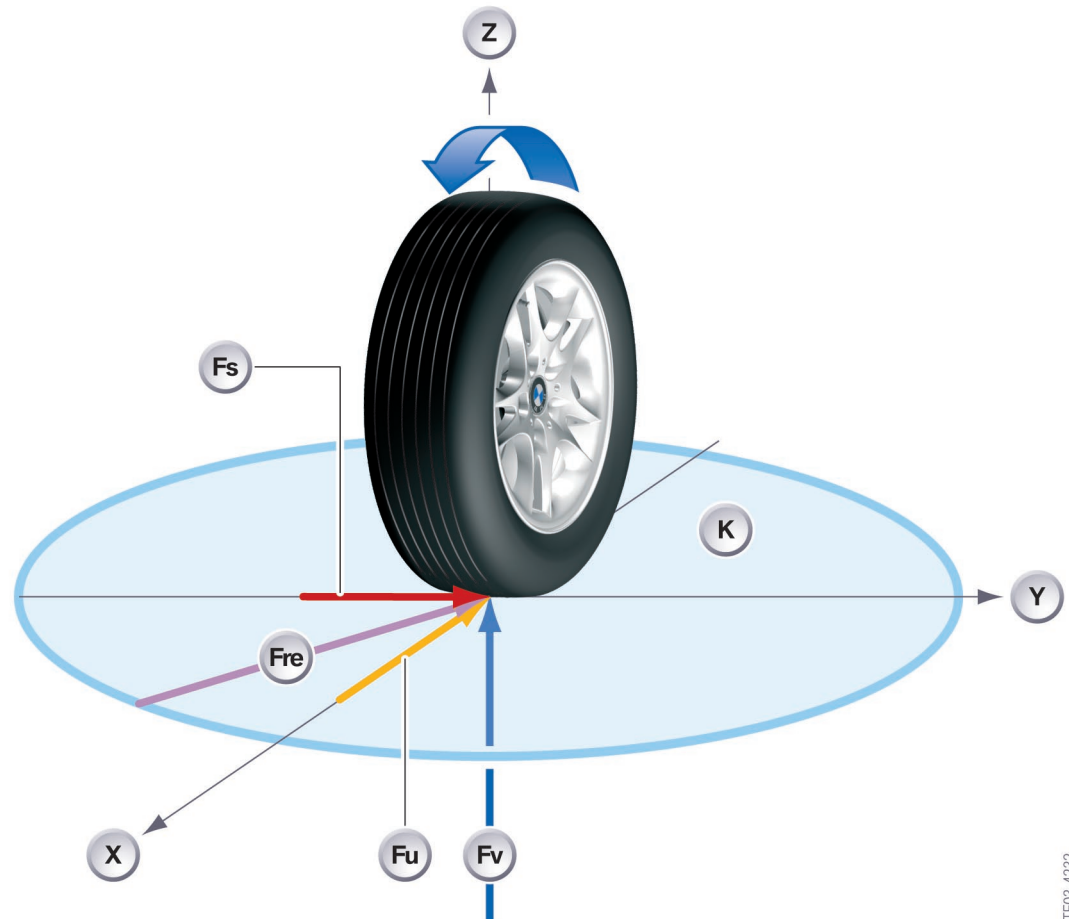
Where a new car model is concerned, it is normally the engine, the attractive body styling with low drag coefficient or similar aspects which impress first.

It is the chassis, however, that is the deciding factor where safety, comfort and driving feel are concerned. The chassis covers the wheel suspensions, wheels, springs, shock absorbers, front and rear axle, steering and brakes. On some vehicles, the chassis also includes a "subframe," a type of auxiliary frame which brings together all the main chassis assemblies.

This auxiliary frame is connected to the bodywork by means of thick rubber mounts (silent blocks) which prevent wheel rolling noise from entering the passenger compartment.

The chassis connects the vehicle with the road. Both force and drive torque are transferred to the road via the chassis. The

chassis also has to absorb all cornering forces when the vehicle is cornering.



TF03-4232

3 - Forces at the wheel

Index	Explanation	Index	Explanation
Fv	Wheel contact force	Fre	Resulting force
Fu	Driving force	K	Maximum force
Fs	Cornering force	X, Y, Z	Co-ordinate axes

The chassis is therefore exposed to a huge number of forces and moments all of which act in different ways. It is essential that all these forces and moments can be transmitted in an optimum way via the tyre contact areas. As vehicles get more powerful and demands for ride comfort and driving safety rise, so the demands placed on the modern chassis increase considerably too. The subject of chassis is so comprehensive, that this seminar will concentrate just on axle geometry and steering. Axle alignment using

the customer services measuring rig and the sections on suspension/damping/axles will be covered in other seminars. The SIPs on tyres/wheels and chassis control systems will complete the overall chassis series.

To begin with, this brochure will explain some axle geometry and chassis terms and will then go on to deal with the reference parameters required for axle alignment operations. Finally, the relevant axle geometry variables will be explained.

Requirements of a modern steering system

- Ensure steerability adapted to the driving conditions
- Function, comfort and safety aspects taken into account
- Vibration damping
- Transfer of relevant road surface information to the driver
- Wheels return after cornering



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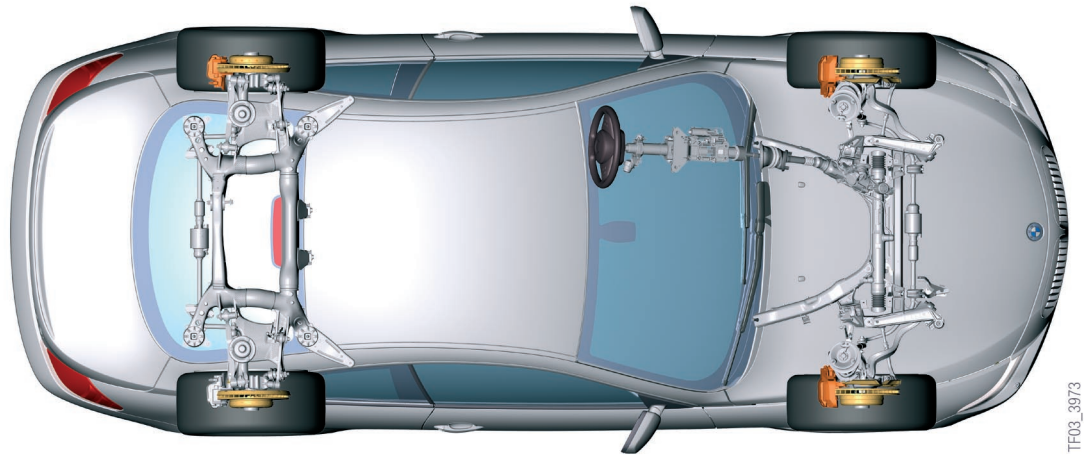
Today, a passenger car steering system is expected to carry out a host of different tasks. It is no longer sufficient just to move the vehicle in the desired direction. The steering process must take function, comfort and safety aspects into account. The vehicle should follow even slight steering movements precisely and on target, without the driver having to make any further corrections at the steering wheel.

However, the vehicle should not respond too directly. Rash steering wheel movements should not result in the vehicle swerving. The steering forces at the wheel should not increase excessively when performing slight steering actions, for example when driving in a straight line at high speed. A high level of comfort is expected.

Comfort also means that the number of steering wheel turns should not be so high as to make parking a nuisance. To ensure that the vehicle can be kept safely under control at high speeds as well, the steering system must ensure good contact with the road. The driver should still be able to "feel" the road surface quality. On the other hand, road surface unevenness, such as potholes and expansion joints, should not snatch the steering wheel out of the driver's hands or start the vehicle yawing. Likewise, poorly balanced wheels should not cause excessive steering wheel vibrations. As a result, quite a lot is demanded of the steering system in terms of vibration damping.

It must be designed so that it is possible to transfer relevant road surface information and filter out any interference. After each steering manoeuvre, the steering wheel is expected to return smoothly to the centre position.

Modern axle geometry must therefore enable the vehicle to be guided and in the process provide feedback to the driver regarding driving conditions and road surface quality.



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4 - Top view of the chassis of the E63

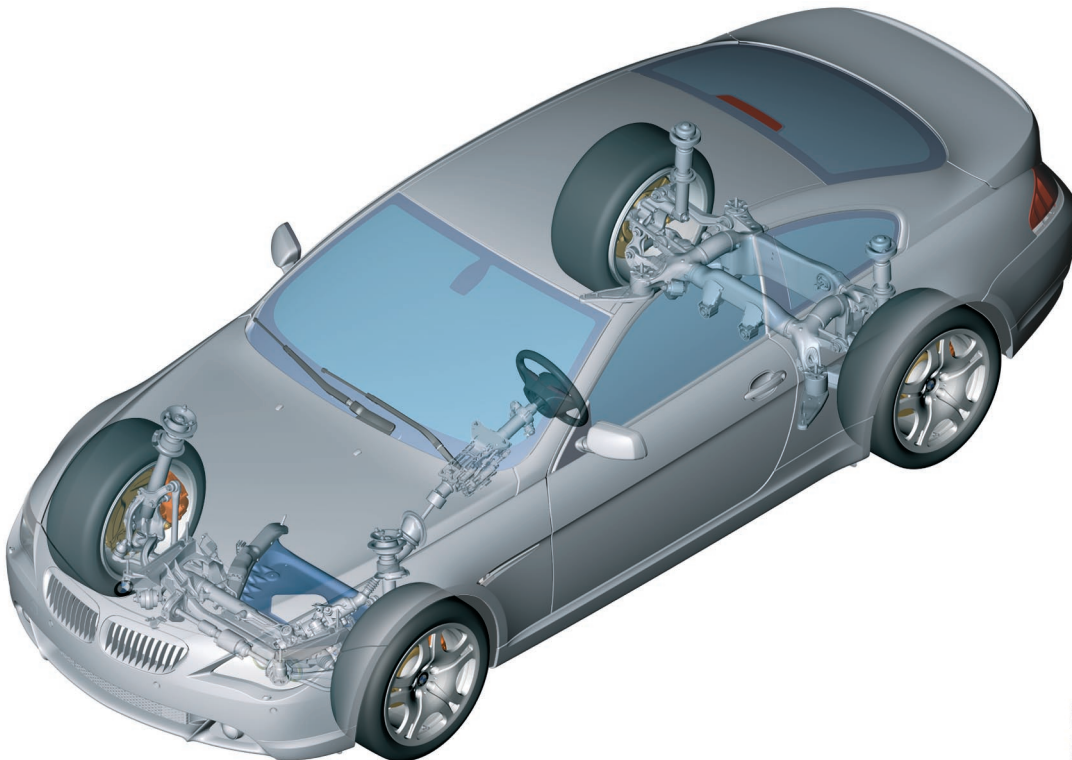
System overview

Basic principles Chassis

The overall chassis system

This section will present the chassis system. The overall system consists of the wheel suspensions, axles and wheels/tyres. The chassis system is responsible for transmission between the road and the vehicle and determines the vehicle's handling

performance. The chassis system consists of both its components and also geometric parameters, which will also be regarded as components here. These parameters form part of the contents of this document and are briefly and clearly presented in this section.



1 - The chassis of the E63

TF04-4571

Wheel position



2 -

The wheel positions are what give a chassis its properties. The wheel position describes the geometric position of the wheel with respect to the body and road. This position is determined by a host of different geometric parameters. Some of these parameters can be determined directly in the course of an axle alignment operation. Others are the result of the kinematic relationships arising during steering movements.

The wheel position is extremely important:

- For ensuring correct straightline running performance.
- For ensuring good tyre adhesion during cornering.
- For tyre wear.

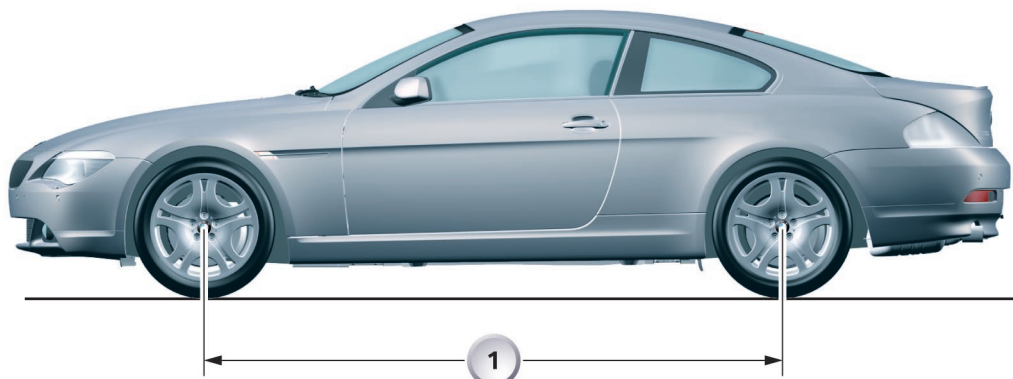
The wheel position is determined by:

- **Wheelbase**
- **Track width**
- **Track**
- **Camber**
- **Spread**
- **Caster**
- **Steering roll radius**
- **Toe-differential angle**

Wheelbase

The wheelbase is the distance between the wheel contact points of the two wheels on the

same side of the vehicle. This distance changes when the suspension moves.



3 - Wheelbase (1) Distance between the centre points of the wheels

TF03-4200

Track width

The track width is the distance between the wheel contact points of the two wheels of one axle. The distance changes when the suspension moves.

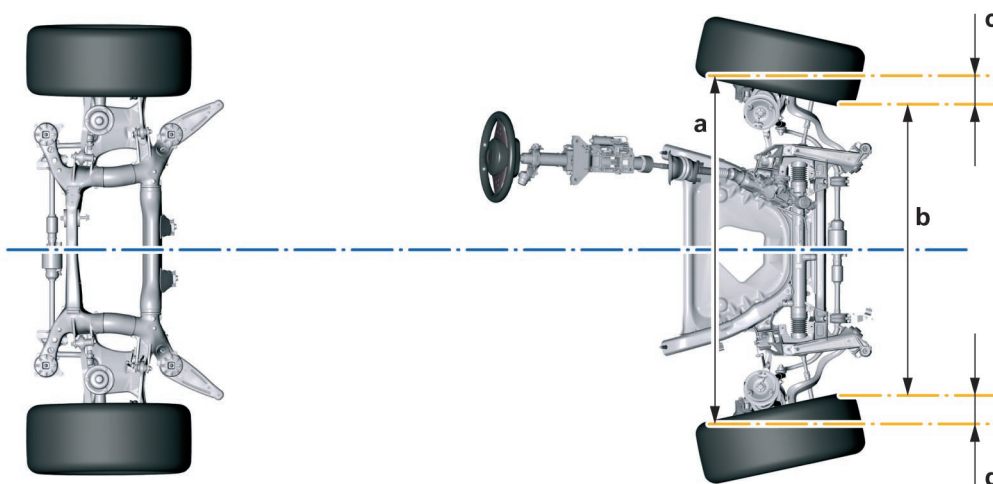


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4 - Track width (1)/Distance between the centre points of the wheels

Track

The total track of an axle is the difference in the distance between the front of the wheels and the rear of the wheels on the same axle.



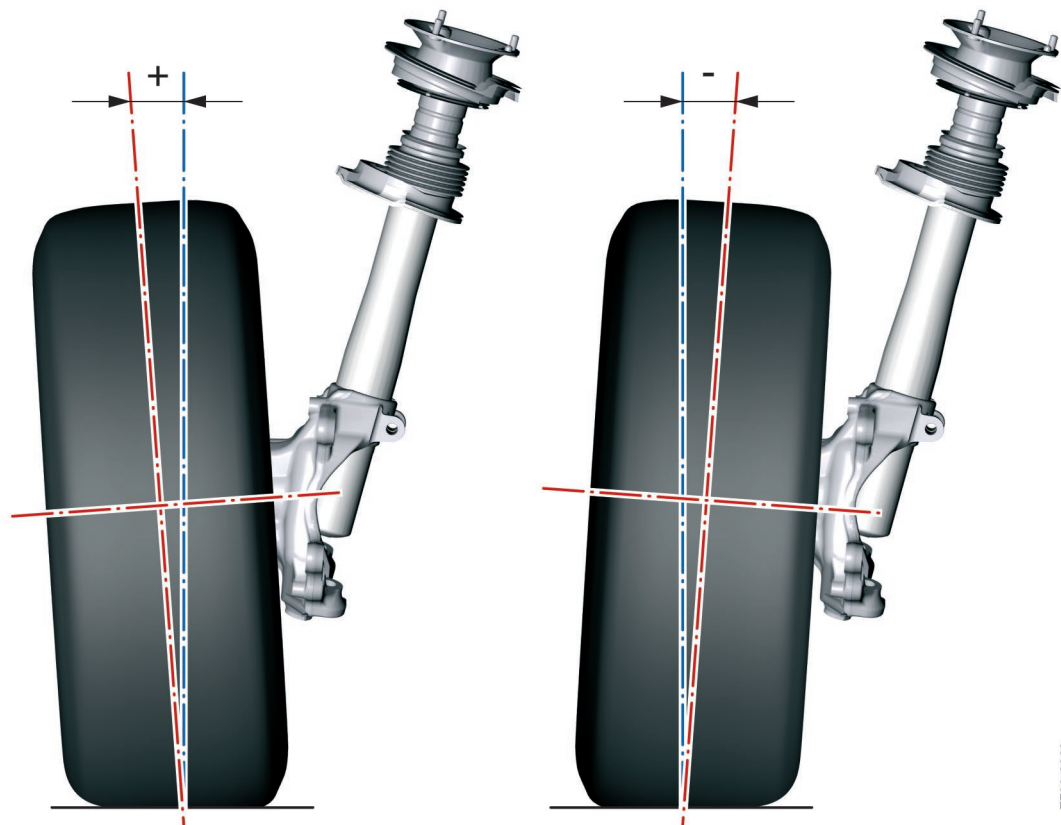
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5 - Total track (c + d) = a - b

Camber

The camber is the angle between the wheel centre plane and a perpendicular line (in the wheel contact point) with respect to the road plane. It is **positive (+)**, if the upper part of the

wheel is angled outwards from the wheel centre plane and **negative (-)** if it is angled inwards. The camber is measured in degrees.



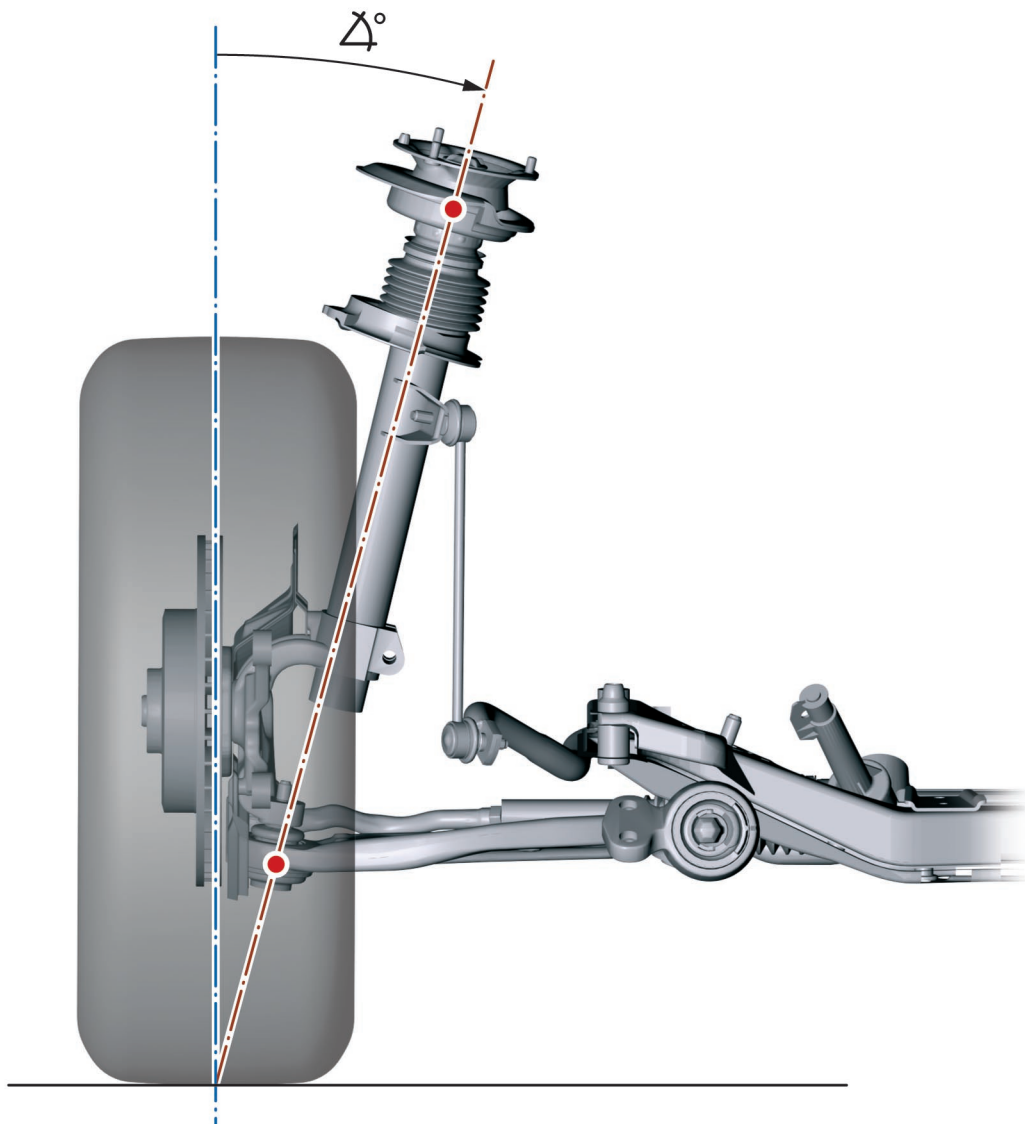
6 - Camber/positive (+)/negative (-)

TF03-3969

Spread

The spread (red) is the inclined position of the pivot axis with respect to a perpendicular line (blue) through the wheel contact point with the road (seen in the direction of the vehicle

steering axle). The spread raises the vehicle when the steering wheel is turned, which generates aligning forces.

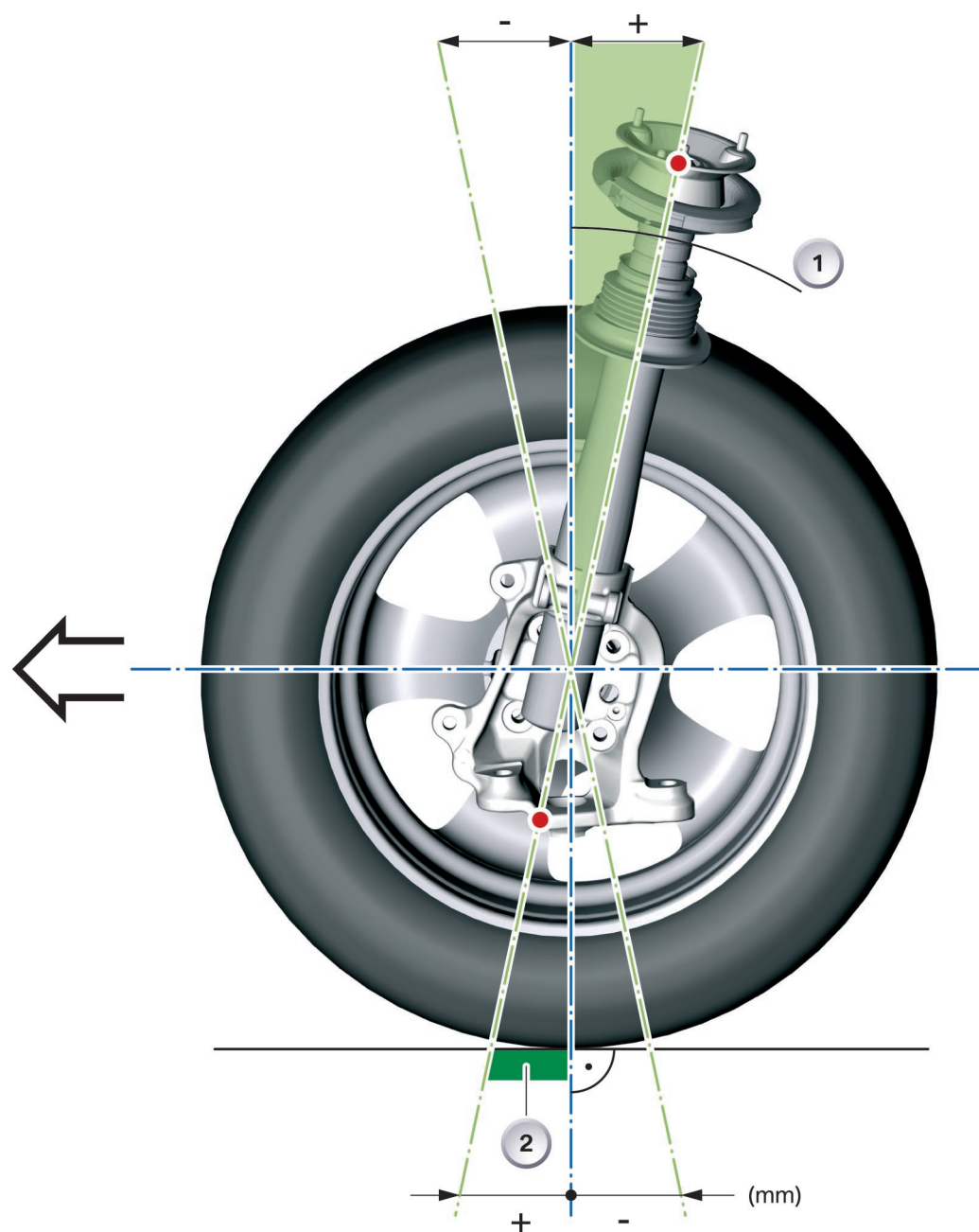


7 - Spread/inclined position of the pivot axis towards the centre of the vehicle

Caster

Caster is the inclined position of the pivot axis in the direction of the vehicle's longitudinal axis.

Index	Explanation
1	Caster angle
2	Caster offset



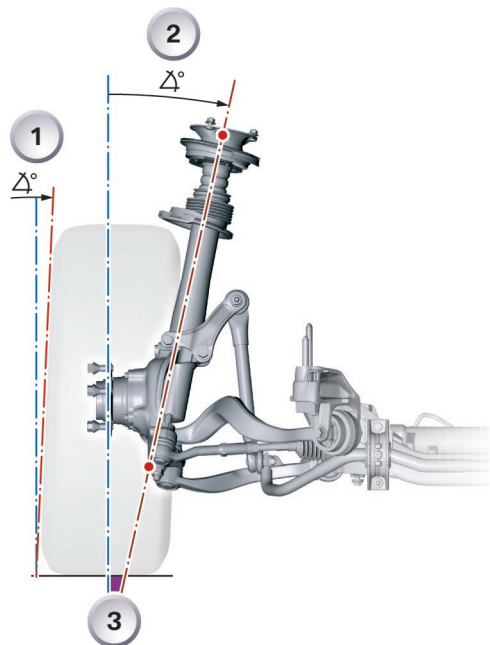
8 - Caster angle (1)/Caster offset (2)

TF03-3971

Steering roll radius

The steering roll radius is the distance from the line of intersection of the wheel centre plane with the road to the piercing point of the extended pivot axis with the road.

Index	Explanation
1	Camber
2	Spread
3	Steering roll radius

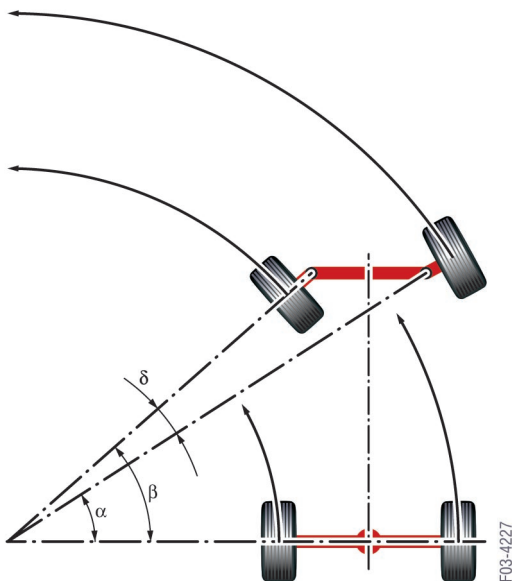


9 - Negative (-) steering roll radius

TF03-3976

Toe-differential angle

The toe-differential angle is the angular difference between the wheels on the inside and outside of the turn.



10 - Toe-differential angle $\delta = \beta - \alpha$

TF03-4227



Functions

Basic principles Chassis

Explanation of terms

This section explains terms that are frequently used in connection with axle geometry.

Wheel position



determined directly in the course of an axle alignment operation. Others are the result of the kinematic relationships arising during steering movements.

The wheel position is extremely important:

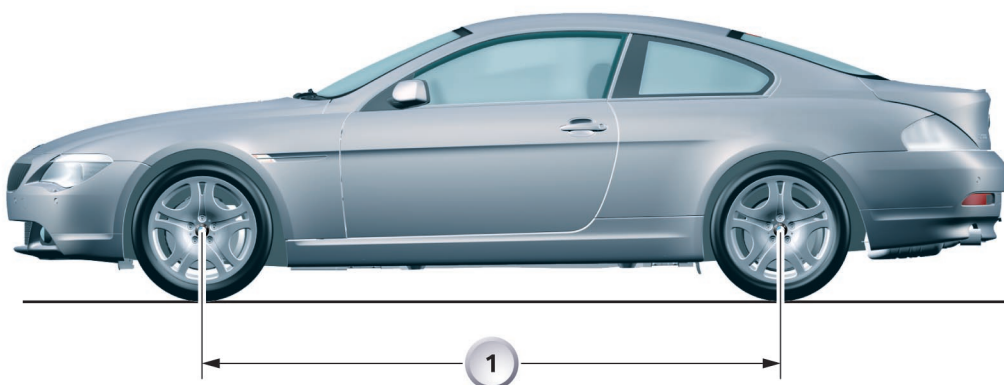
- For ensuring correct straightline running performance.
- For ensuring good tyre adhesion during cornering.
- For tyre wear.

The position of the wheel influences how the vehicle handles during cornering. A distinction is made between:

- **Understeer**
- **Oversteer**
- **Neutral steer**

1 -
The wheel positions are what give a chassis its properties. The wheel position describes the geometric position of the wheel with respect to the body and road. This position is determined by a host of different geometric parameters. Some of these parameters can be

Wheelbase

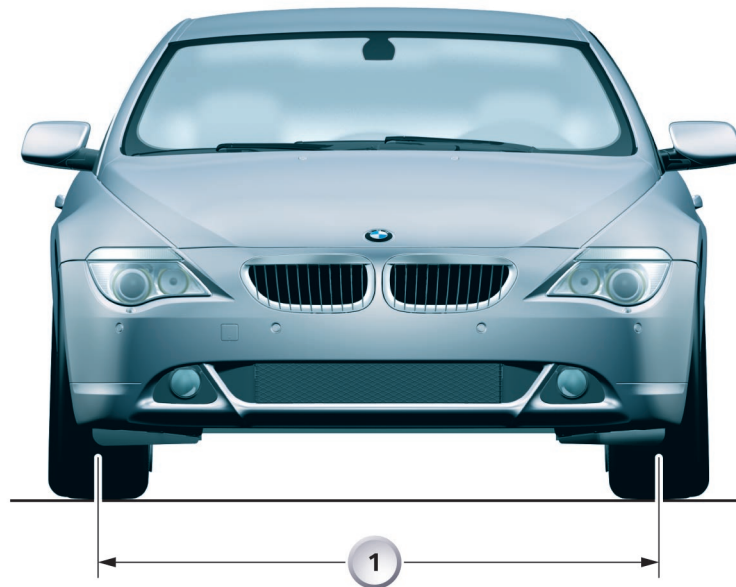


2 - Wheelbase (1) Distance between the centre points of the wheels

The wheelbase is the distance between the centre of the wheels on the front axle and the centre of the wheels on the rear axle. In the case of multi-axle vehicles, the individual wheelbases are given in order, from front to rear.

A large wheelbase means more useful space, better ride comfort and less tendency to pitch. By contrast, a short wheelbase makes tight cornering easier.

Track width



TF03-4201

3 - Track width (1)/Distance between the centre points of the wheels

The track width is the distance from the centre of one wheel to the centre of the other wheel on the same axle. The track width considerably influences a vehicle's cornering performance. A wide track width allows the vehicle to take corners at higher speeds. In the case of independent wheel suspension, with control or semi-trailing arms, a change in track width occurs during wheel compression and rebound. Roll resistance and tyre wear increase as a result. If the change in track width is too great, the vehicle's straightline stability deteriorates.

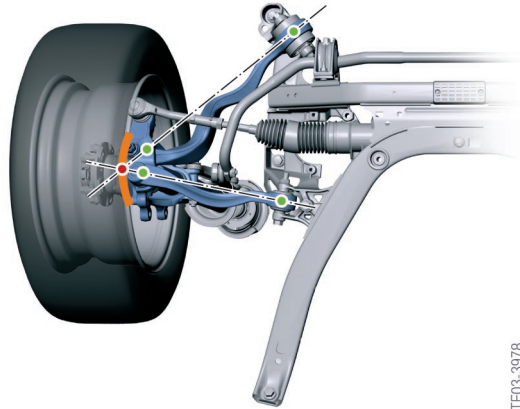
Pivot axis/Steering axis



4 - Pivot axis/Steering axis

The pivot axis (red) is the effective axis about which the wheel being steered is turned. In reality, this should not be the centre axis of an axle component (e.g. suspension strut). It lies on the line connecting the upper and lower pivot points of the wheel suspension. The design dictates that the upper pivot point is in the centre of the spring strut support bearing. The lower pivot point is in the outer ball joint of the control arm.

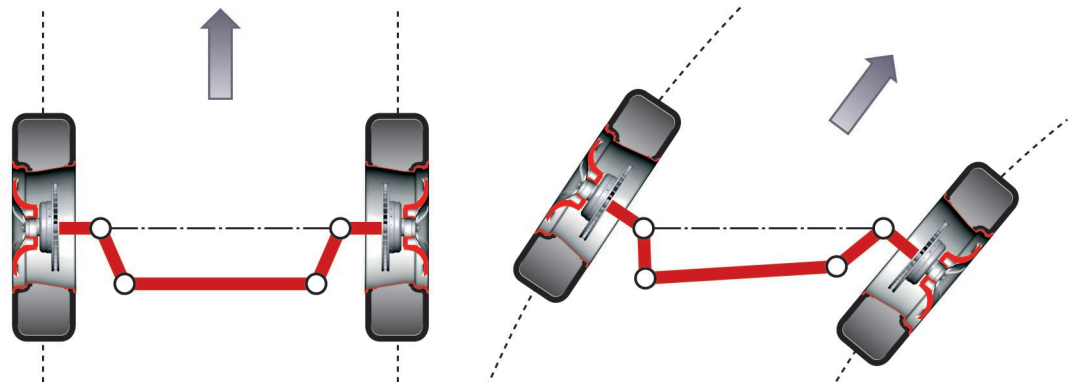
Wheel suspension kinematics can cause this axis to move when the steering angle changes.



5 - Universal joint McPherson axle / Determining the lower pivot point

Note the special feature of the universal joint McPherson axle in this regard. The effective lower pivot point is the intersection of the effective extensions of the lower arms. This point is not static but dependent on the respective steering angle.

Steering trapezoid

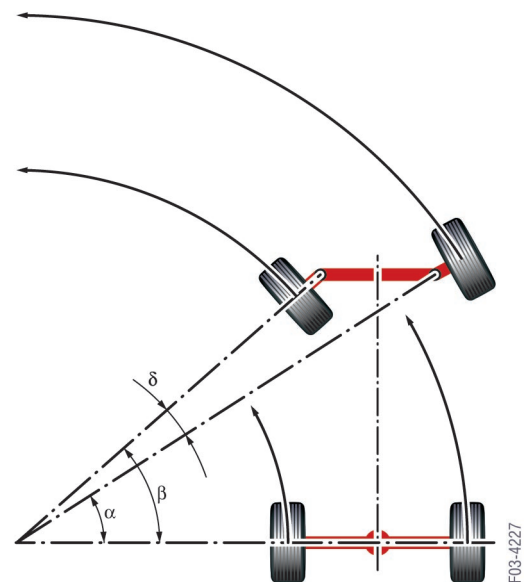


6 - The steering trapezoid enables the steered wheels to be turned at different angles.

Optimum adhesion between tyre and road is only guaranteed if the tyre contact area runs along the road surface (static friction) and is not pushed (sliding friction). If the rubber tyre is pushed over the road surface, power cannot be transferred. This transfer capability will be affected even if just individual areas of the effective tyre contact area are being pushed by interfering forces (e.g. lateral forces/braking forces).

When cornering, the wheels of the one axle cover different distances. If both wheels were turned at the same angle, one of the two wheels would not be able to follow its natural path. Each wheel is affected by the other wheel and is forced out of its natural path by the occurring lateral forces. The wheels "grind" on the road. This increases tyre wear and impairs driving safety. For the wheels to run without any sliding movement, the wheel on the inside of the turn must be turned in more than the wheel on the outside of the turn.

The front axle, steering arm and track rod together form the steering trapezoid. This geometric shape enables a toe-differential angle to be established, in other words, the wheels on the inside and outside of the turn can be turned at different angles.



7 - The steering trapezoid enables all wheels to turn about a common cornering centre point.

The toe-differential angle is the difference in the steering angle between the wheels on the inside and outside of the turn.

$$\delta = \beta - \alpha$$

Kinematics

From a physics point of view, kinematics are the laws which give rise to sequences of movements.

Where chassis engineering is concerned, kinematics is the sequence of movements at

the wheels and wheel-guiding components. Kinematics therefore have a direct effect on the position of the wheel for the respective load conditions.

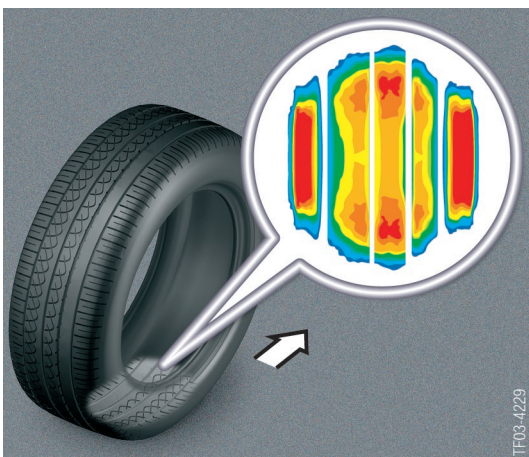
Tyre contact area



The tyre contact area is the area which is covered by the wheel standing on the road.

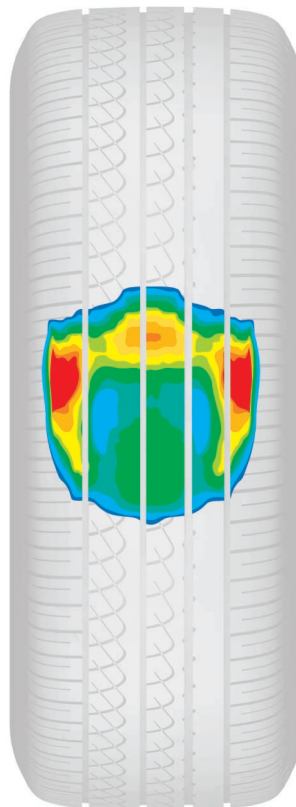
Tyre contact patch

The tyre contact patch is the effective contact area of a tyre in operation. It is therefore the tyre contact area which is deformed by interfering forces (lateral forces, braking and acceleration forces) and by road surface quality.



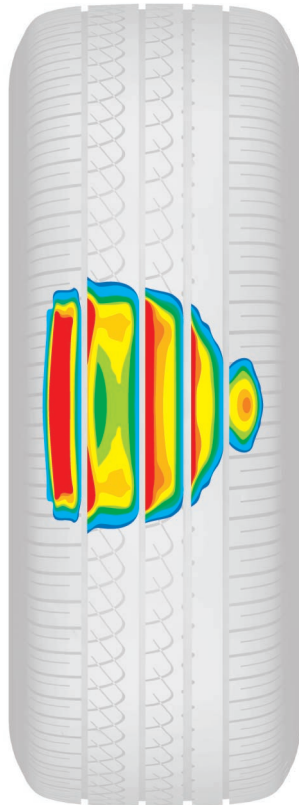
8 - Tyre contact patch / Dynamic tyre contact area

The tyre contact patch therefore describes the area of road which is touched by the tyre when the vehicle is in operation.



9 - Tyre contact patch affected by braking force

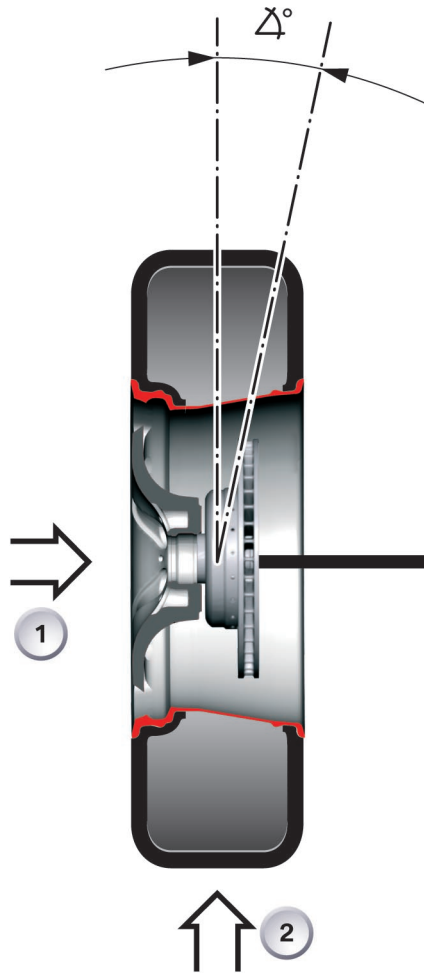
The sum of these dynamic wheel contact areas represents the direct connecting link between the road and the vehicle. All acceleration (drive axle only), deceleration and lateral forces must be transmitted via this resulting overall area.



TF03-4230

10 - Tyre contact patch affected by lateral force, e.g. cornering

Slip angle

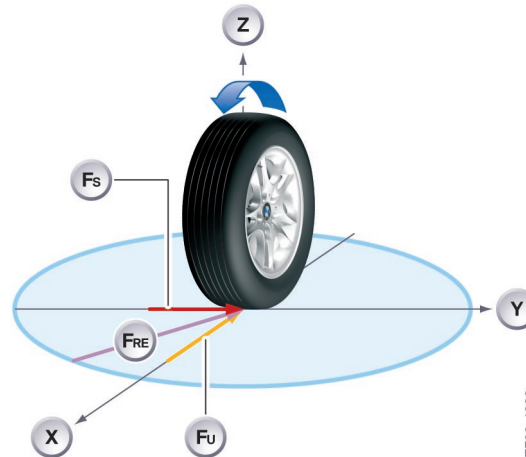


11 - Slip angle (viewed from above)

Index	Explanation
1	Lateral force
2	Driving force

The slip angle is the angle which the wheel plane forms with the direction of travel (wheel's direction of movement). If lateral forces (e.g. wind forces, centrifugal forces) are acting on a vehicle as it is moving along, the direction of travel of the wheels will change: They will run at an angle to the original direction of travel.

If the slip angle is the same at the front and rear, the vehicle is said to have neutral steer. If the slip angle is greater at the front, this produces understeer; if it is greater at the rear, there is oversteer.



12 - Lateral force and driving force form a resulting force

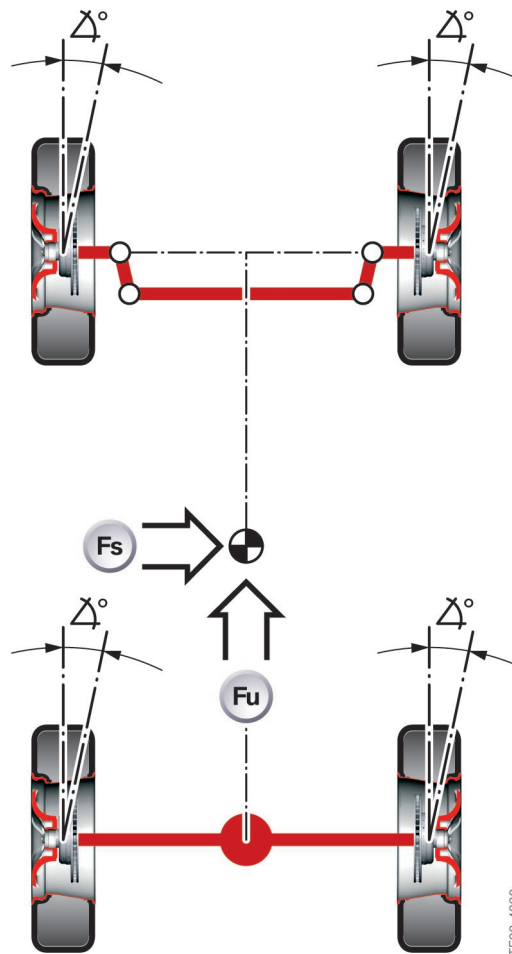
Index	Explanation	Index	Explanation
F _v	Wheel contact force	F _{re}	Resulting force
F _u	Driving force	K	Maximum force
F _s	Cornering force	X, Y, Z	Co-ordinate axes

The slip angle is dependent on:

- Wheel load
- Lateral force
- Tyre design
- Tyre profile
- Tyre pressure
- Coefficient of friction

Special terms relating to cornering

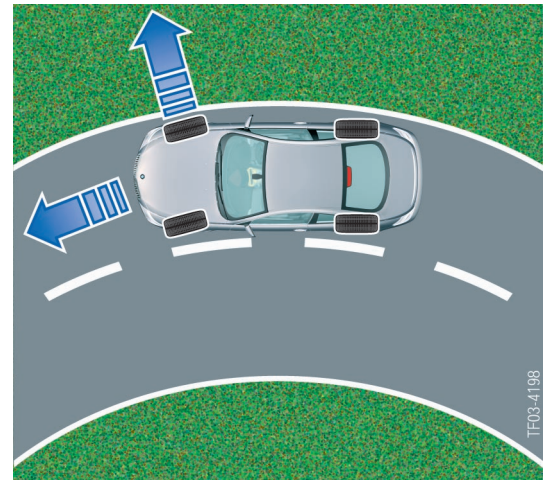
A vehicle's cornering performance is also referred to as its self-steering properties. This handling performance is considerably influenced by the changing ratio of lateral force to wheel load on the front and rear axles. Lateral force increases as centrifugal force increases.



13 - Neutral steer: All slip angles are the same

Neutral steer

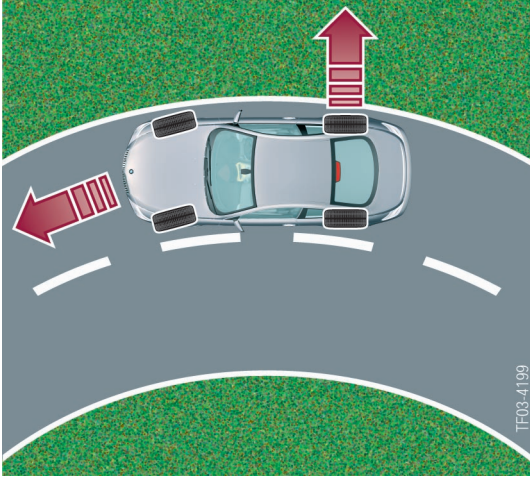
The slip angles arising as a result of lateral force are the same on the front and rear axles. Neutral cornering facilitates the best use of lateral forces and thereby the highest limit cornering speeds. However, it also reduces the subjective feel for vehicle stability. In addition, vehicle breakaway cannot be calculated as it can occur via both the front and rear axles.



14 - Understeer / Vehicle slides outwards via the front axle

Understeer

The ratio of lateral force to wheel load is greater on the front axle than on the rear. The vehicle follows a larger cornering radius than that corresponding to the steering angle. It also slides to the outside of the turn via the front axle. When designing the chassis, this behaviour is often the preferred option, because when the vehicle breaks away it can be returned to a straightline course which it is possible to calculate. Take, for example, a vehicle which begins to break away via the front axle whilst being driven to the limits; if the steering angle is then reduced, the vehicle will recover to assume a straightline course. BMW chassis are designed so that they have slight understeer characteristics.



15 - Oversteer / Vehicle slides outwards via the rear axle

Oversteer

The ratio of lateral force to wheel load is greater on the rear axle than on the front. The vehicle follows a smaller radius than that corresponding to the steering angle. The vehicle slides to the outside of the turn via the rear axle.

Reference parameters

The following terms are reference parameters which are required to carry out axle alignment and assess the axle kinematics.

Wheel contact point/wheel centre plane

Wheel contact point

The wheel contact point is the intersection of a perpendicular line, going through the axis of rotation, and the road surface plane. It is located in the wheel centre plane.

Because the wheel deforms when exposed to forces, it is possible that the wheel contact point will not correspond to the geometric centre of the tyre contact patch.

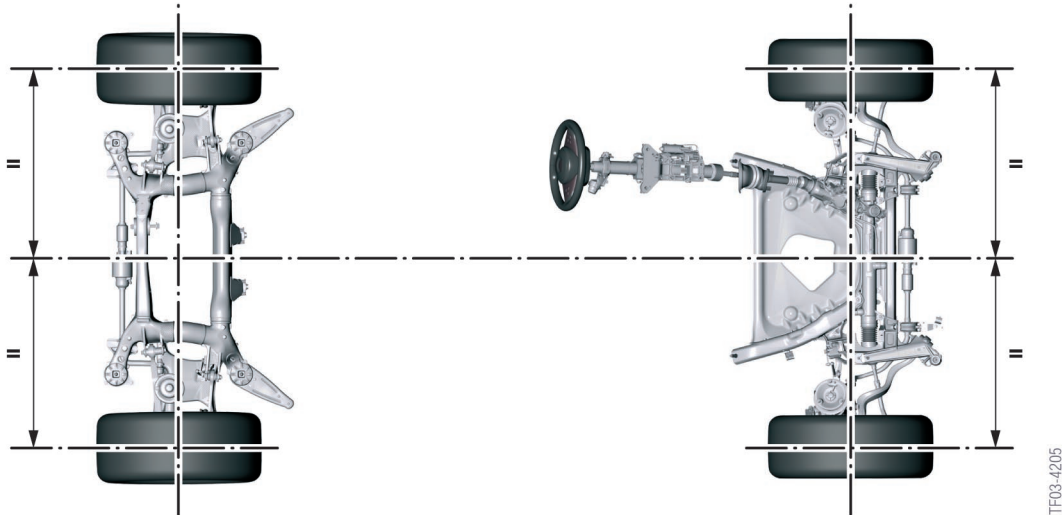


Wheel centre plane

The wheel centre plane intersects the wheel's axis of rotation vertically in the centre of the tyre.



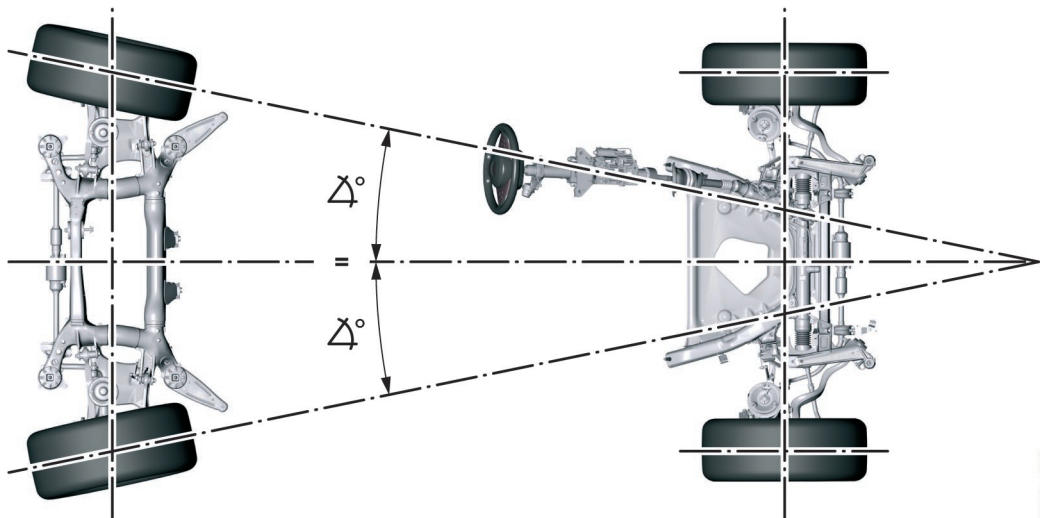
Vehicle longitudinal centre plane



16 - The vehicle longitudinal centre plane / The plane located at the centre of the track widths

The vehicle longitudinal centre plane is vertical to the road surface. This plane follows the same direction as the line joining the centres of the front and rear track widths.

Geometrical axis



17 - Geometrical axis

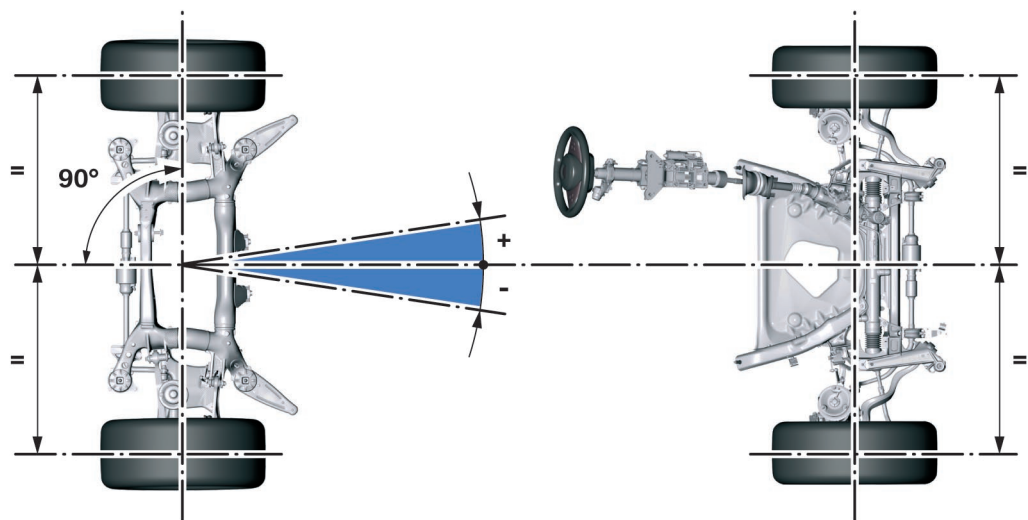
The geometrical axis is the angle bisector of the total toe-in angle of the rear axle. If this straight line deviates from the vehicle centre plane, a driving axis angle is produced and the vehicle will "dog track."

Geometric chassis variables

The following section explains the axle geometry variables. This is a general presentation of the geometric parameters and the effect they have, in terms of kinematics, on the chassis system as a whole. When adjusting these variables, it is essential that this is done with respect to a specific vehicle, and always with setpoint values and using

information specific to that vehicle. These variables quite often determine other variables and influence each other. This will be highlighted under **Interaction**. Each description will be followed by notes on diagnosing (**Fault symptoms**) and **Work instructions** for repair.

Driving axis angle



18 -

The driving axis angle is the angle between the vehicle longitudinal centre plane and the geometric axis. It is positive if the geometric axis is pointing to the front left.

Interaction

The driving axis angle is produced from the track value, lateral offset and the inclined position of the rear axle

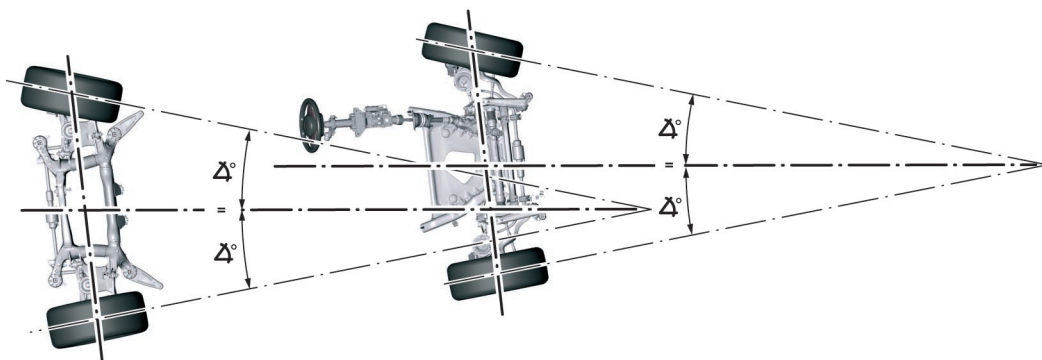
Fault symptoms

If the driving axis angle has a value $\neq 0^\circ$, the vehicle will run offset and will "dog track" (see work instructions in the section on track).

Straight ahead drive

This wheel position, where the front wheels must have the same individual track values, with respect to the vehicle longitudinal centre plane, is used to assist alignment operations. The term **does not necessarily mean** that

the vehicle is driving in a straight line. It merely describes the position of the front wheels with respect to the rear axle. The front wheels are positioned at the same angles as the rear wheels.



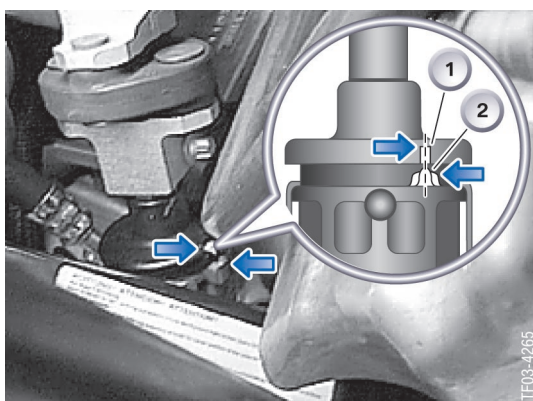
19 - Straight ahead drive / Angle bisectors of the total front and rear track are parallel with each other

Fault symptoms

The vehicle's steering wheel is off-centre when driving in a straight line. The driving axis angle does not equal 0°. If the rear axle wheels have different individual track values, the front wheels will have to be turned slightly for **straightline driving**. This is necessary in order to bring the angle

bisectors of the respective total track for the front and rear axles parallel. In this front wheel position, the individual front wheel track values refer to the geometric axis, as the vehicle longitudinal centre plane and the geometric axis differ.

Steering centre point



20 - Steering centre point / Mark on steering gear

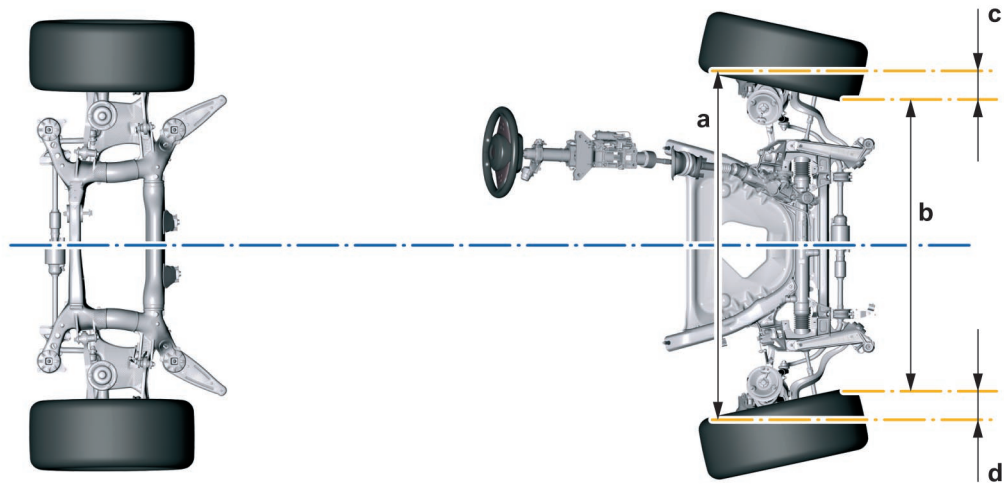
Move steering to the straight ahead position at the steering gear so that the marks on the steering gear (2) and steering column (1) are aligned. This ensures the wheels are turned the same for both left and right steering inputs.

Work instructions

To move the wheels to the straight-ahead position, turn the steering from one steering lock to the other. Turn back half the number of steering turns and do not make any fine adjustments to the mark on the steering gear until this stage. This procedure ensures that the operation check can be performed over the vehicle's entire steering range.

Index	Explanation
1	Mark on steering column
2	Mark on steering gear

Track



21 - Total track (c + d) = a - b

The total track of an axle is the difference in the distance between the front of the wheels and the rear of the wheels on the same axle. The track is measured at the height of the wheel centre at the rim flanges. An electronic axle alignment procedure measures the angle of the wheel centre plane to the vehicle longitudinal centre plane (when aligning the rear axle) and to the geometric axle (when aligning the front axle). A value in angle degrees is calculated. The measuring procedure remains the same.

Toe-in

(positive +) means the distance between the wheels of the axle in question is less at the front than at the rear.

Toe-out

(negative -) on the other hand is where the distance between the rim flanges of the axle in question is greater at the rear than at the front.

Track 0

is where the centre planes of the wheels of one axle are parallel with each other.

The toe-in or toe-out stabilizes the straightline running of the wheels by twisting the tyre contact patch. In this way it is possible to reduce the tendency of the wheels to shimmy by disconnecting the wheels from the play in the wheel suspension and in the steering transmission components. The track value selected for a specific vehicle concept depends essentially on the type of drive. The aim is for track to be as near to 0 as possible when driving. It is therefore possible to achieve the correct response to the typical behaviour of a type of drive by selecting the appropriate track value. The front wheels of rear-wheel drive vehicles tend to run out from each other. This tendency is counteracted by means of a toe-in. On front-wheel drive vehicles, the tendency of the wheels to run inwards towards each other is counteracted with a toe-out.

Individual track

The individual track on the front axle means the angle of a wheel with respect to the geometric axis. The individual track on the rear axle means the angle of a wheel with respect to the longitudinal centre plane.

Work instructions

If the individual track values on the rear axle differ, proceed as follows:

- For straightline running, the front wheels must be turned until the angle bisector of the total front axle track is parallel with the angle bisector of the total rear axle track (= geometric axis).

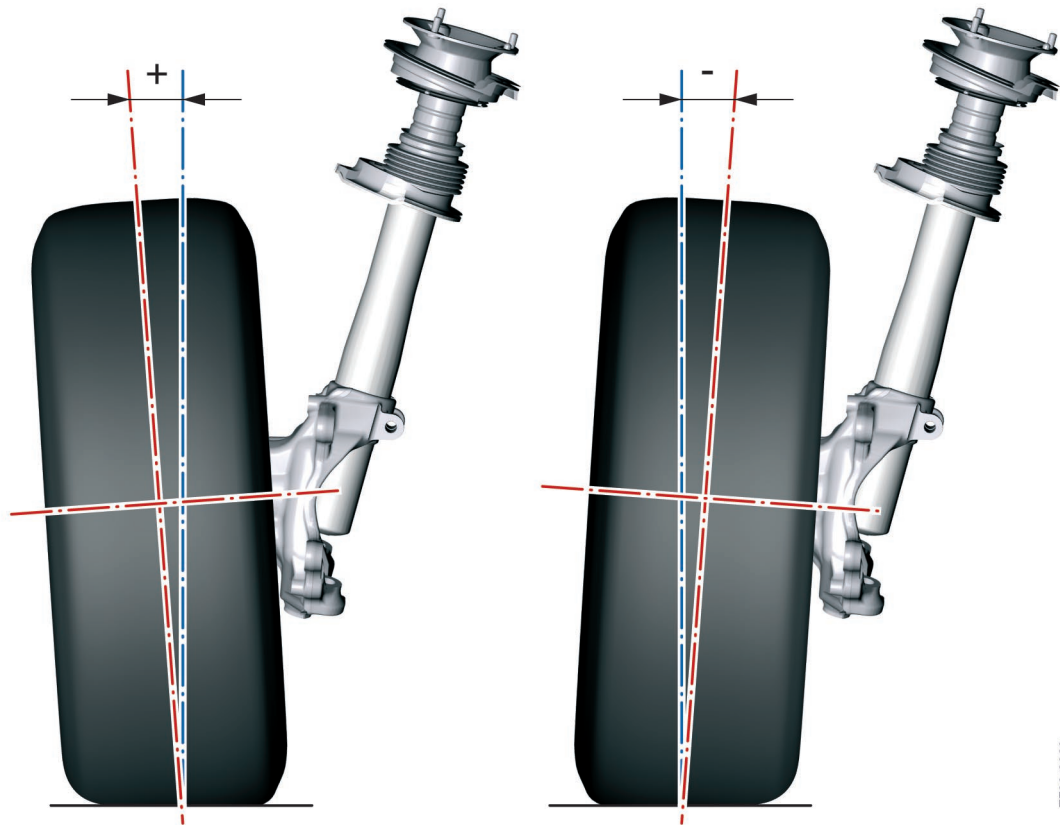
The vehicle will run out of line as a result. (See Straight ahead drive)

If a vehicle has different individual track values on the rear axle, the steering angle will adjust itself during vehicle operation. The steering wheel will then be off-centre.

Fault symptoms

- Excessive negative track (toe-out): Tyre wear on the inside, poor straight-line running performance
- Excessive positive track (toe-in): Tyre wear on the outside, poor straight-line running performance

Camber



22 - Camber/positive (+)/negative (-)

The camber is the angle between the wheel centre plane and a perpendicular line (in the wheel contact point) with respect to the road plane. It is **positive (+)** if the upper part of the wheel is angled outwards from the wheel centre plane and **negative (-)** if it is angled inwards. The camber is measured in degrees. Wheels running at a camber want to follow a circular path, like an overturned cone. When they are prevented from doing this by the wheel suspension, a lateral force in the direction of the vehicle centre plane arises (negative camber). For this reason, the potential of the tyres to transfer lateral forces is greater with negative camber than with positive camber. During vehicle operation, the wheel is also running on the hub carrier, taking the strain off the outer wheel bearings and compensating for wheel bearing play.

Positive camber

Older vehicles often had a positive camber on the front axle. The design made this necessary, as the tapered roller bearings would not withstand any other type of load. In

a steering manoeuvre, the front axle wheel on the outside of the turn is shifted to the negative camber range by the caster angle and the spread. The desired cornering stability is achieved in this way. When cornering, **no** positive camber should arise at the outer wheel of the steered axle.

Negative camber

On modern BMW chassis, it is possible to set a negative camber for the straight-ahead position on the front axle as well. This has been made possible by using two rows of ball bearings.

The rear wheels on BMWs have always had a negative camber.

This is a compromise.

The wheels on the rear axle cannot be shifted to the negative camber range by steering movements. To improve cornering stability, a negative camber has to be pre-set.

TF03-3969

Interaction

Camber has an indirect influence on steering roll radius. The wheel contact point continues to shift in the direction of or away from the vehicle longitudinal axis. For this reason, the camber changes a steering roll radius parameter.

The camber also influences track, and must therefore be set before the track is set.

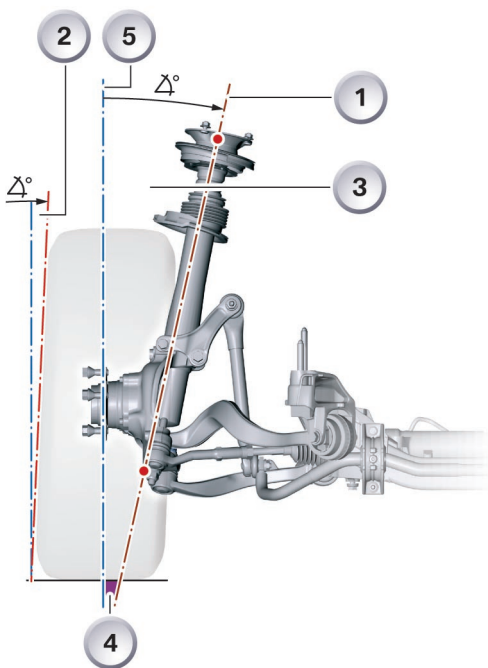
Fault symptoms

Excessive camber (negative): causes increased tyre wear on the inside of the wheels and increases tyre flexing.

Cornering stability improved. However, excessive camber at high speeds and with high axle loads causes the tyre shoulder areas to heat up excessively. This can cause tyre damage (tyres overheating, inner wear).

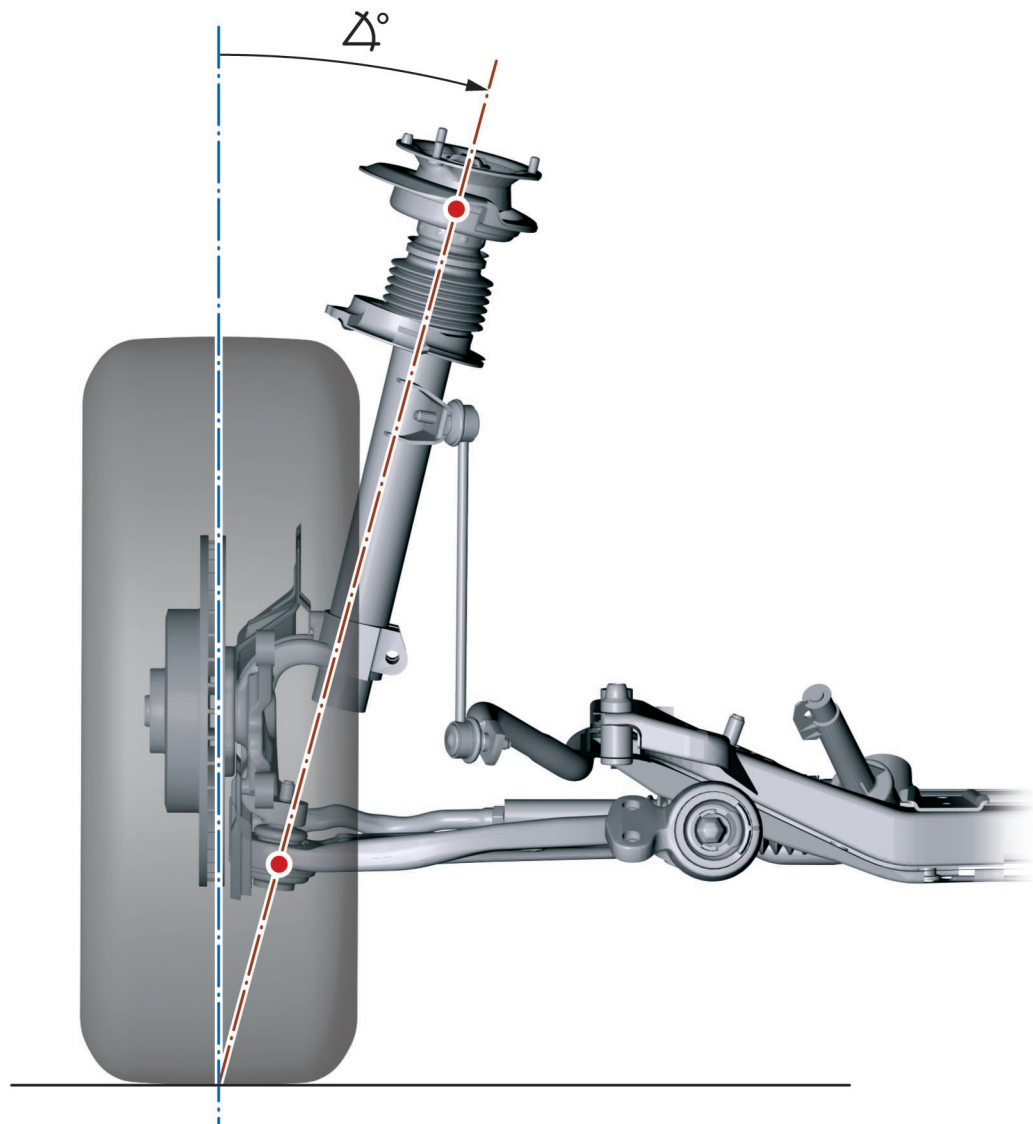
The front axle will also demonstrate excessively aggressive steering properties.

Camber too low (positive): Cornering stability worsens, increased outer tyre wear.



Index	Explanation
1	Pivot axis
2	Camber
3	Spread
4	Steering roll radius
5	Perpendicular line in the wheel contact point

Spread



TF03-4226

23 - Spread / Inclined position of the pivot axis towards the centre of the vehicle

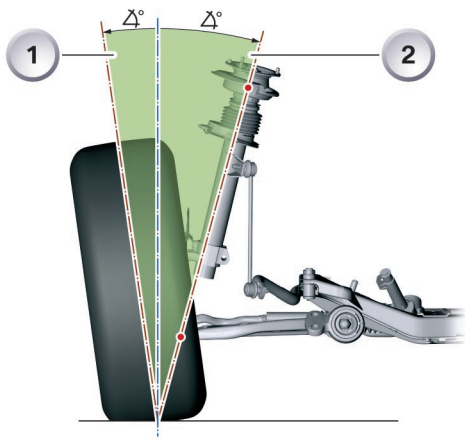
The spread (red) is the inclined position of the pivot axis with respect to a perpendicular line (blue) through the wheel contact point with the road (seen in the direction of the vehicle steering axle). The spread raises the vehicle when the steering wheel is turned, which generates aligning forces.

Interaction

The spread has a direct influence on the steering roll radius.
The steering roll radius is dependent on:

- The position of the piercing point of the extended pivot axis with the road and
- The distance of the piercing point from the wheel contact point.

The spread therefore has an effect on how interfering forces are transmitted (see Steering roll radius). During steering manoeuvres, spread and the caster lift the body. This generates a wheel alignment force on account of the increased wheel load.



TF03-4264

24 - The sum of camber angle (1) and spread angle (2) remains constant during wheel compression.

1 = camber angle

2 = spread angle

For a large proportion of BMW axles, the spread and camber together form an angle which remains the same during wheel compression and rebound.

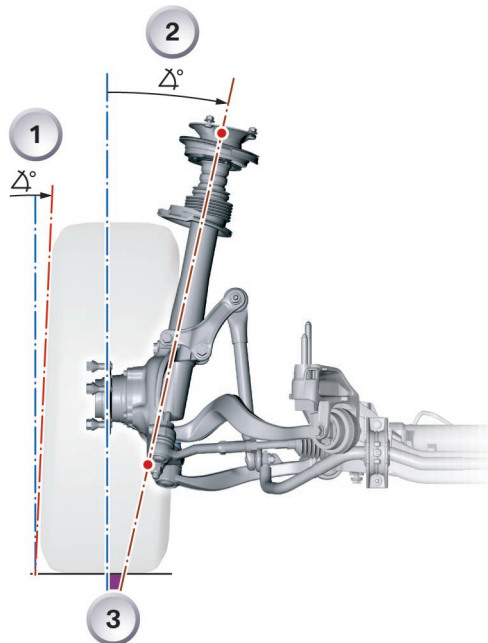
Work instructions

The spread is measured indirectly by applying a steering angle of 20°

Fault symptoms

- Spread too large: high steering and holding forces
- Spread too small: poor steering return, prone to tyre faults (conicity, angle effect), may cause vehicle to pull to one side
- Spread different on left and right-hand sides of vehicle: vehicle prone to pulling to one side.

Steering roll radius



25 - Negative (-) steering roll radius

1 = camber

2 = spread

3 = steering roll radius

The steering roll radius is the distance from the line of intersection of the wheel centre plane with the road to the piercing point of the extended pivot axis with the road.

This distance is called a **positive (+) steering roll radius** if it is pointing inwards from the wheel contact point to the vehicle centre plane.

It is called a **negative (-) steering roll radius** if it is pointing outwards from the wheel contact point

If the extended pivot axis intersects the road surface at the wheel contact point exactly, the **steering roll radius is 0**.

The steering roll radius is a lever arm which influences the steering by means of a torque. Forces caused by the braking effect, different friction surfaces or obstacles (wheel compression and rebound) take effect at the wheel. This produces the desired effect, namely the creation of aligning forces when cornering. The driver is helped to steer the vehicle back. However, this has a negative effect in straightline driving conditions as the interfering forces may be transmitted to the steering and via the steering wheel to the driver.

Influence of braking forces:

Positive (+) steering roll radius:

If a vehicle is braked more on one side (as a result of road surface quality or the brakes pulling on one side), the vehicle is pulled to the side on which the greater braking force is acting. This is because the pivot point about which the steering roll radius, as the lever arm, is acting is on the inside of the wheel. If the steering roll radius is positive, the forces acting on the wheel push the wheel outwards. The wheel which is transmitting the greatest braking force is pivoted outwards more. As a result, the vehicle is steered more in the direction of the side being braked more heavily.

Negative (-) steering roll radius:

By using rims with large offsets, it is possible to shift the steering roll radius to the outer half of the tyre contact patch. This is more difficult to achieve on large, powerful saloons because the wheel disc does not have enough space for a brake suitably adapted to the vehicle. As a result, BMW has developed the universal joint McPherson strut axle which allows virtually any steering roll radius to be set.

The negative steering roll radius cause the wheels to pivot inwards when braking. The wheel with the greater braking force continues to pivot inwards which creates automatic countersteer. The vehicle is steered away from the side being braked more heavily and thereby remains virtually on track. A variable steering roll radius utilizes the positive elements and avoids the negative ones. This type of response has been achieved using the universal joint McPherson axle.

Interaction

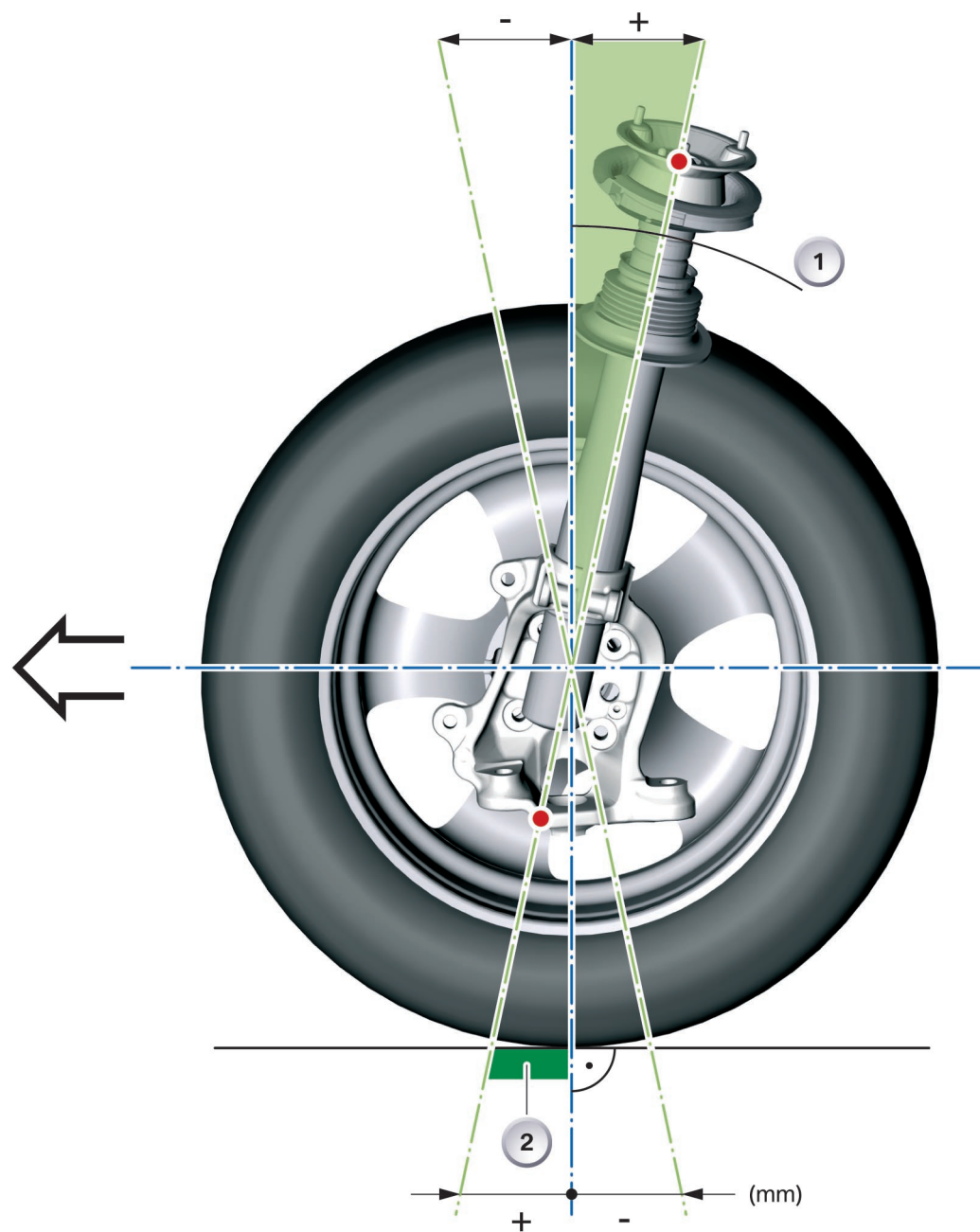
The steering roll radius is influenced by the camber, spread and the rim offset.

TF03-3976

Summary of properties:

- **Positive steering roll radius (+):**
Produces stable straightline running performance, but requires the driver to countersteer in the event of uneven braking.
- **Negative steering roll radius (-):**
In the event of uneven braking, automatically introduces countersteering, so that the driver only has to keep the same steering position.
- **Steering roll radius 0:**
In the event of brake pull to one side or tyre faults, prevents the transmission of interfering forces to the steering.
High steering forces when stationary.

Caster



26 - Caster angle (1) / Caster offset (2)

Index	Explanation
1	Caster angle
2	Caster offset

TF03-3971

The caster is the inclined position of the pivot axis towards the vehicle longitudinal axis with respect to a perpendicular to the road. If the caster is positive (+), the wheel contact point is behind the piercing point of the extended pivot axis (the wheels are pulled), which has a track-stabilising effect. If the caster is negative (-), the wheel contact point is in front of the piercing point of the extended pivot axis (the wheels are pushed). In chassis construction, this is undesirable because it would have a destabilising effect.

Interaction

The caster and spread lift the vehicle body during steering manoeuvres. This brings about a wheel alignment force because of the wheel load.

Fault symptoms

- Caster too positive (+): high steering and holding forces
- Caster too negative (-): poor steering return, prone to tyre faults (conicity, angle effect), may cause vehicle to pull to one side - wheel shimmy - sensitivity to side winds
- Caster different on left and right-hand side of vehicle: vehicle prone to pulling to one side.

Work instructions

Like spread, the caster is measured indirectly by applying a steering angle of 20°.

Caster angle

The caster angle is the angle which is formed by the pivot axis and a perpendicular to the road surface. This angle creates the track-stabilising effect of caster. As speed increases, the wheel is guided more stably, in terms of direction. Because the wheel is being pulled against the direction of travel, on account of the inclined position of the pivot axis, this angle is also responsible for reducing wheel shimmy tendency.

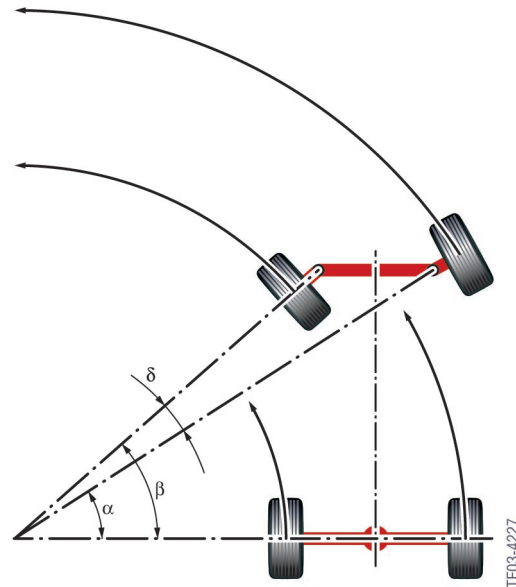
Interaction

When the wheel is turned, the caster angle generates a negative camber in the wheel that is on the outside of the turn.

Caster offset

Caster offset is the distance between the wheel contact point and the piercing point of the extended pivot axis. It therefore describes the lever arm in the tyre contact patch about which the wheel is trailing. This lever arm is responsible for ensuring that relatively high forces have to be applied to change the direction of the wheel. This makes it more difficult to turn a moving wheel. The interaction of **caster offset** and **caster angle** can be used to achieve directionally stable, steering-friendly handling; this is done by positioning the pivot axis further back. In this way, the caster offset can be reduced but the caster angle retained.

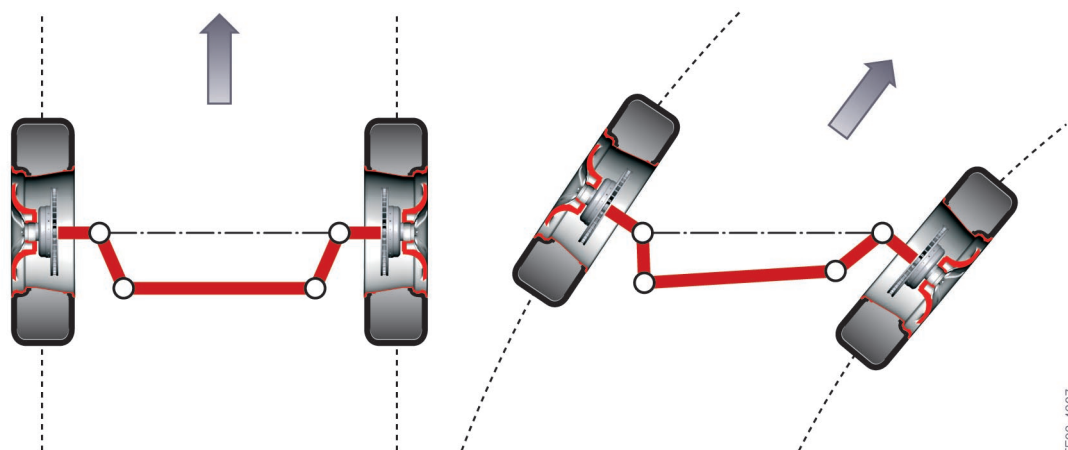
Toe-differential angle



27 - Toe-differential angle $\delta = \beta - \alpha$

The toe-differential angle is the angular difference between the wheels on the inside and outside of the turn. The Ackermann steering system is designed in such a way that the angular position of the wheels to each other changes as the steering angle increases. The toe-differential angle gives you an idea of

how the steering trapezoid is working when the steering is turned to the left and right. If set correctly, the toe-differential angle will be the same for both left and right-hand steering inputs, taking into account permissible angular tolerances. **(Explanation of steering trapezoid)** Front axle, steering arm and track rod together form the steering trapezoid. When cornering, the steering trapezoid enables the wheels on the inside and outside of the turn to be turned at different angles. When the vehicle is driving in a straight line, the track rod is parallel to the centre line of the front axle. The position of the centre line cannot be changed. To corner, the steering must be turned via the steering knuckle. The steering knuckle and steering arm are positioned at an angle to each other which does not change. The trapezoidal layout of the components means that when the steering arm is pushed, the track rod moves out of its parallel position with the centre line of the front axle. The second steering arm is thereby turned about its swivel point on the front axle. The resulting angular difference (toe-differential angle) between the angles of the steering arms increases as the steering angle increases.



28 - The steering trapezoid

Work instructions

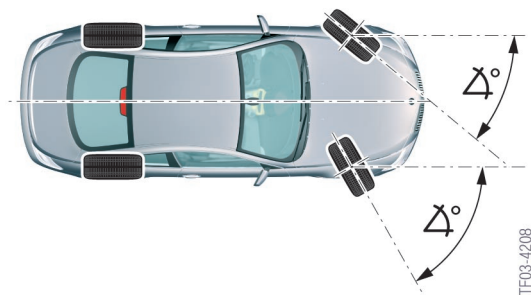
Measurement done by turning the wheel on the inside of the turn by 20°. The toe-in is taken into account in the measurement.

Fault symptoms

- Loss of adhesion in tyre contact patch

- Tyres squeal when cornering
- Increased tyre wear
- Vehicle breaks away when cornering
- Poor steering return with large steering inputs

Maximum steering angle



29 - Maximum steering input

The maximum steering angle is the angle of the centre plane of the inner and outer wheels with the steering wheel at full left- and right-hand lock (in relation to the longitudinal centre plane of the vehicle). The maximum steering angle has an influence on a vehicle's turning circle.

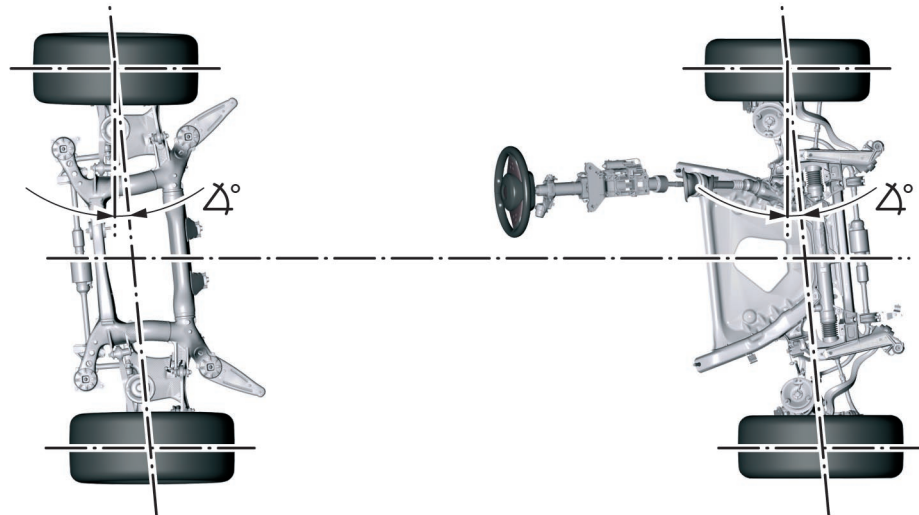
Work instructions

In the case of vehicles with recirculating ball steering, the centre position of the steering lever must be checked as otherwise the steering trapezoid will be at an angle. This will be evident from the different toe-differential angles. Measuring the maximum steering angle in conjunction with the steering wheel position may help in this regard.

Effect of faults

- Vehicle has different turning circles.

Wheel offset angle

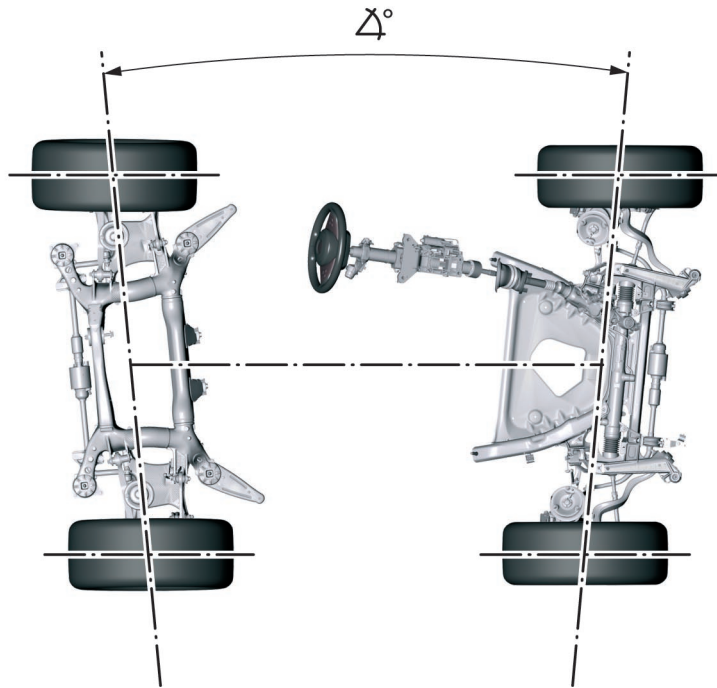


30 - Wheel offset angle

The wheel offset angle is the angle deviation of the line joining the wheel contact points from a line which runs at 90° to the geometric axis. The wheel offset angle is positive if the right-hand wheel is offset forwards and negative if it is offset to the rear.

TF03-4210

Wheelbase differential

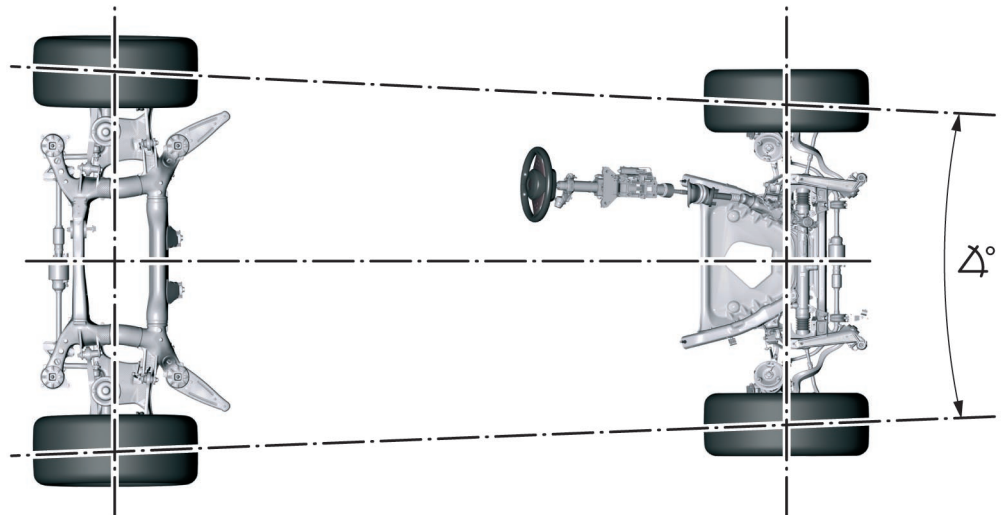


31 - Wheelbase differential

The wheelbase differential is the angle between the line joining the front wheel contact points and the line joining the rear wheel contact points. The angle is positive if the wheelbase on the right-hand side is greater than that on the left-hand side and negative if vice versa. The wheelbase differential affects cornering.

TF03_4213

Track width differential



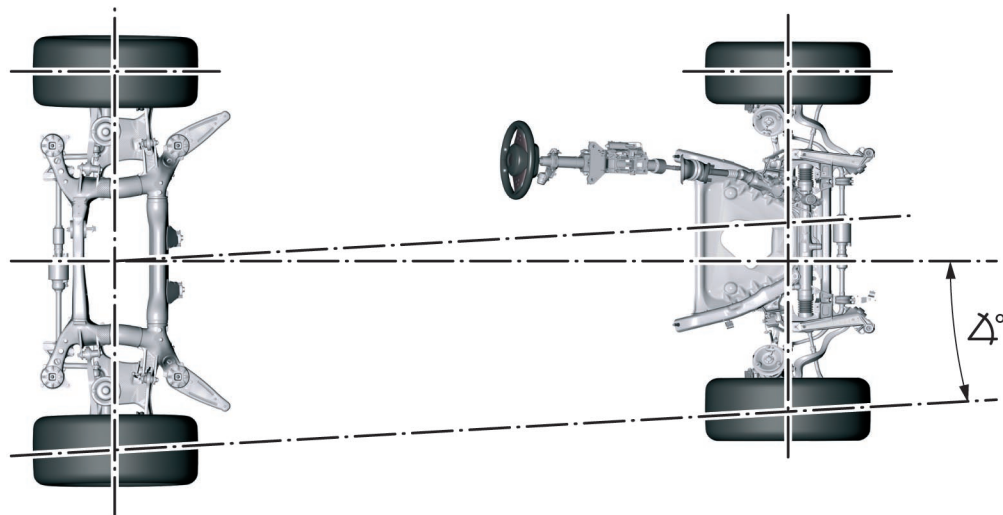
TF03-4211

32 - Track width differential

The track width differential is the difference between the track widths of the front and rear axles. It is measured in degrees. For this, the position of the lines joining the wheel contact points on the left and right-hand sides of the

vehicle with respect to each other is calculated. The track width differential is positive if the rear track width is greater than the front. A track width differential may indicate **possible bodywork damage**.

Lateral offset

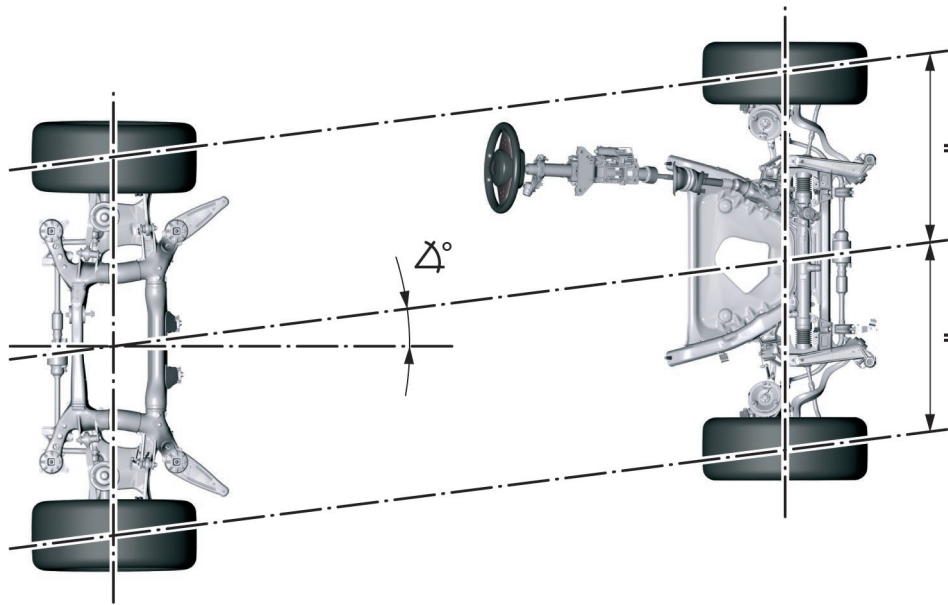


TF03-4212

33 - Lateral offset

The lateral offset is the position of the line joining the wheel contact points on one side of the vehicle, with respect to the geometric axis. This offset is positive if the rear wheel is offset outwards, with respect to the front wheel. This angle may also indicate **possible bodywork damage**.

Axle offset



TF03-4214

34 - Axle offset angle

The axle offset angle describes the angle between the angle bisectors of the track width differential and the geometric axis. The axle offset angle is regarded as positive if the rear axle is offset to the right. This angle may also indicate **possible bodywork damage**.





Service information

Basic principles Chassis

This section contains information relevant to servicing operations. The items are assigned to the respective axle geometry parameters.

Driving axis angle

Interaction

The driving axis angle is produced from the track value, lateral offset and the inclined position of the rear axle.

Fault symptoms

If the driving axis angle has a value $\neq 0^\circ$ the vehicle will run offset and will "dog track" (see work instructions in the section on Track).

Straight ahead drive

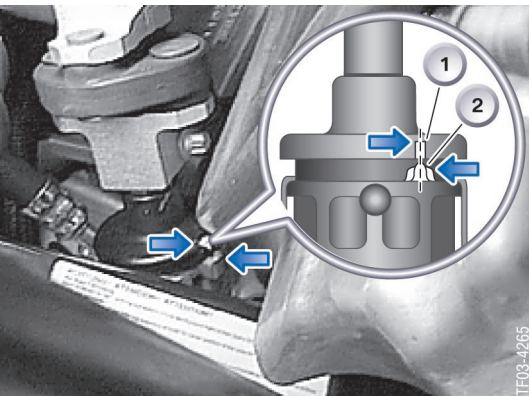
Fault symptoms

Steering wheel is off-centre. Driving axis angle is not 0° .

If the rear axle wheels have different individual toe-in values, the front wheels will have to be turned slightly for **straightline driving**. This is necessary in order to bring the angle

bisectors of the respective total track for the front and rear axles parallel. The wheels only have to be aligned with each other as described if the driving axis angle is $\neq 0^\circ$. In other words if the vehicle longitudinal centre plane and the geometric axis differ.

Steering centre point



1 - Steering centre point / Mark on steering gear

steering turns and do not make any fine adjustments to the mark on the steering gear until this stage. This procedure ensures that the operation check can be performed over the vehicle's entire steering range.

No.:	Description:
1	Mark on steering column
2	Mark on steering gear

Move steering to the straight ahead position at the steering gear so that the marks on the steering gear (2) and steering column (1) are aligned. This ensures the wheel are turned the same for both left and right steering inputs.

Work instructions

To move the wheels to the straight-ahead position, turn the steering from one steering lock to the other. Turn back half the number of

Track

Fault symptoms

- Excessive negative track (toe-out): tyre wear on the inside, poor straight-line running performance
- Excessive positive track (toe-in): tyre wear on the outside, poor straight-line running performance

Individual track

Work instructions

If a vehicle has different individual track values for the rear axle, it will run offset. (See **Straight ahead drive**)

If a vehicle has different individual track values on the rear axle, the steering angle will adjust itself during vehicle operation. **The steering wheel will then be off-centre.**

Camber

Interaction

Camber has an indirect influence on steering roll radius. The wheel contact point continues to shift in the direction of or away from the vehicle longitudinal axis. For this reason, the camber changes a steering roll radius parameter.

The camber also influences the track and must therefore be set **before** the track is set.

Fault symptoms

Excessive camber (negative): causes

increased tyre wear on the inside of the wheels and increases tyre flexing.

Cornering stability improved. However, excessive camber at high speeds and with high axle loads causes the tyre shoulder areas to heat up excessively. This can cause tyre damage (tyres overheating, inner wear). The front axle will also demonstrate excessively aggressive steering properties.

Camber too low (positive): Cornering stability worsens, increased outer tyre wear.

Spread

Interaction

The spread has a direct influence on the steering roll radius.

The steering roll radius is dependent on:

- The position of the piercing point of the extended pivot axis with the road and
- The distance of the piercing point from the wheel contact point.

The spread therefore has an effect on how interfering forces are transmitted (see Steering roll radius). During steering manoeuvres, spread and the caster lift the body. This generates a wheel alignment force on account of the increased wheel load.

Work instructions

The spread is measured indirectly by applying a steering angle of 20°.

Fault symptoms

- Spread too large: high steering and holding forces
- Spread too small: poor steering return, prone to tyre faults (conicity, angle effect), may cause vehicle to pull to one side
- Spread different on left and right-hand side of vehicle: vehicle prone to pulling to one side.

Steering roll radius

Interaction

The steering roll radius is influenced by the camber, spread and the rim offset.

Properties:

- **Positive steering roll radius (+):**
Produces stable straightline running performance, but requires the driver to countersteer in the event of uneven braking.
- **Negative steering roll radius (-):**
In the event of uneven braking, automatically introduces countersteering, so that the driver only has to keep the same steering position.
- **Steering roll radius 0:**
In the event of brake pull to one side or tyre faults, prevents the transmission of interfering forces to the steering. High steering forces when stationary.

Caster

Interaction

The caster and spread lift the vehicle body during steering manoeuvres. This brings about a wheel alignment force because of the wheel load.

may cause vehicle to pull to one side - wheel shimmy - sensitivity to side winds

- Caster different on left and right-hand side of vehicle: vehicle prone to pulling to one side.

Fault symptoms

- Caster too positive (+): high steering and holding forces
- Caster too negative (-): poor steering return, prone to tyre faults (conicity, angle effect),

Work instructions

Like spread, the caster is measured indirectly by applying a steering angle of 20°.

Caster angle

Interaction

When a steering angle is applied, the caster angle changes

the camber of the wheel on the outside of the turn to a negative one.

Toe-differential angle

Work instructions

Measurement done by turning the wheel on the inside of the turn by 20°. The toe-in is taken into account in the measurement.

- Tyres squeal when cornering
- Increased tyre wear
- Vehicle breaks away when cornering
- Poor steering return with large steering inputs

Fault symptoms

- Loss of adhesion in tyre contact patch

Maximum steering angle

Work instructions

In the case of vehicles with **recirculating ball steering** the centre position of the steering lever must be checked as otherwise the steering trapezoid will be at an angle. This will be evident from the different track difference

angles. Measuring the maximum steering angle in conjunction with the steering wheel position may help in this regard.

Effect of faults

Vehicle has different turning circles.





