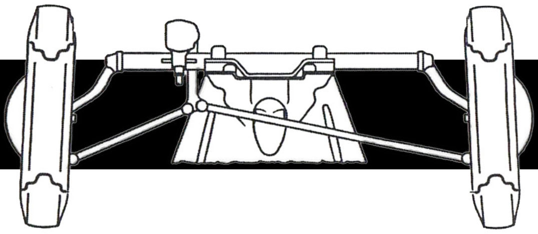
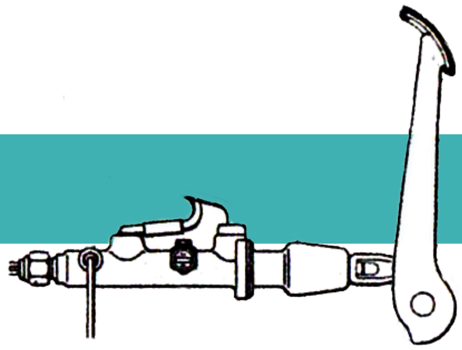
Paruzzi Magazine

Digital Publication for the classic Volkswagen

26

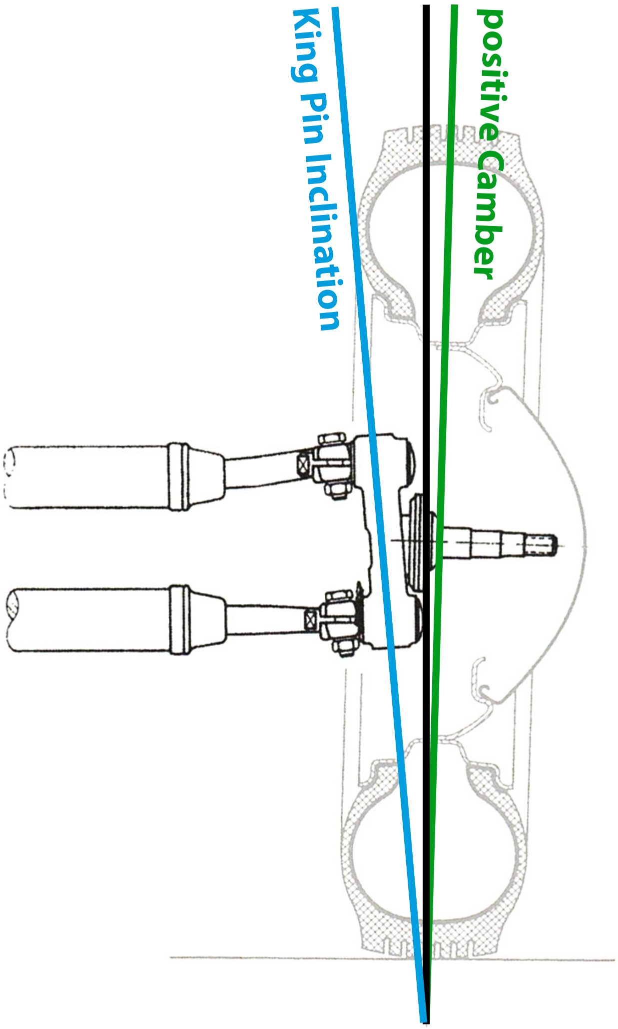




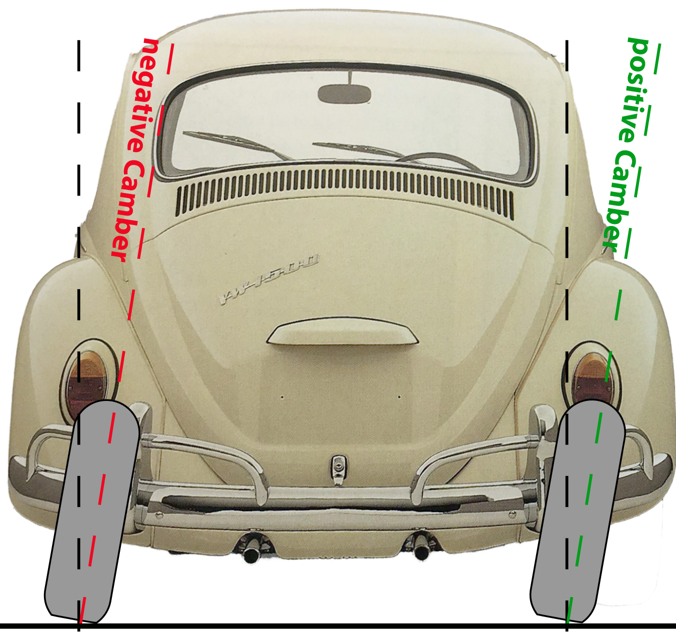
#76 Front and rear axle

Introduction

In the previous edition, we explained what Camber and King Pin Inclination is (KPI). An important consequence of KPI is the Scrub Radius of the front wheels. Before starting this article, read edition 25. Click on the image to the right to read edition 25.



It's probably already become a bit clear from reading that article that there is a lot of science hidden in the chassis and suspension of our classic Volkswagen to optimally position the car on the road surface.

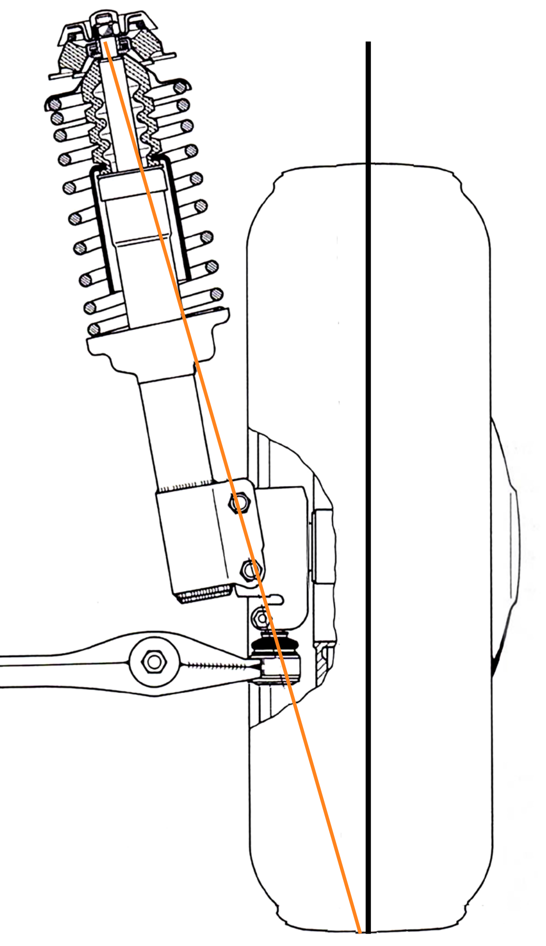


Caster and Toe

It is also starting to become more apparent that adjusting one setting will affect another setting. Also, wrong adjustment of one wheel will affect another.

We saw that replacing the narrow diagonal tires with wide radial tires (photo below) gives the car a rugged look, but sometimes at the expense of steering comfort and handling. Not directly because of the larger tire area, but because of the modification of the Scrub Radius, which will cause the tires to offer too much resistance when turning. Choosing new rims with the correct ET value is part of the study, along with the choice of tire size.

In addition to Camber and KPI, there are other settings that matter, such as Caster and Toe, among others; we will talk about these in this article.



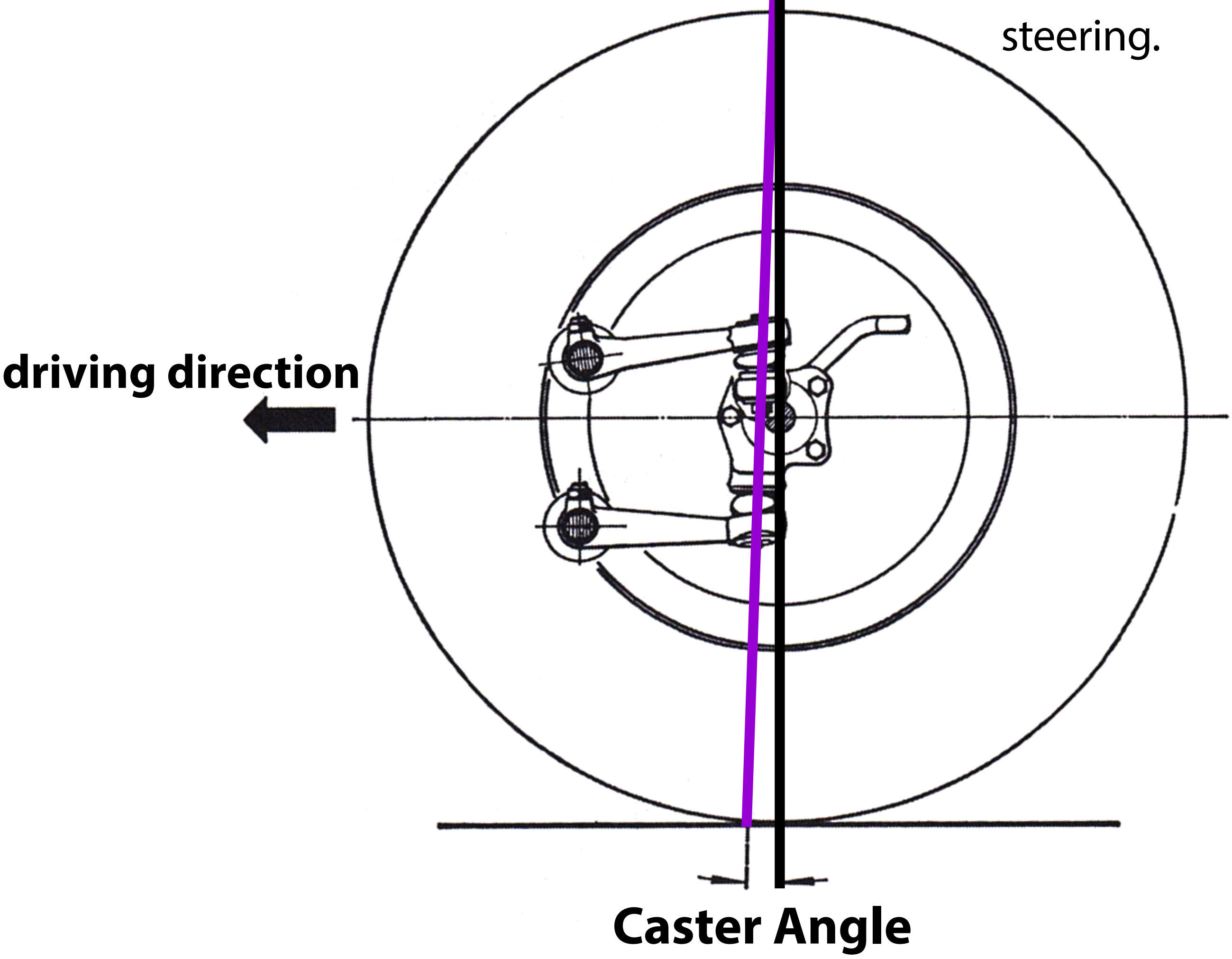
Drawing left: Changing the tire size will affect the Scrub Radius, as we saw in edition 25. When the Scrub Radius becomes too large, the forces in maneuvering have become so great that the car becomes unmanageable. Adjusting one wheel geometry setting will mean a complete review of all the settings, to make the car fit again for the application for which it was initially intended....

#76 Front and rear axle

Caster Angle

Caster Angle (or Caster for short) is a setting related to the front wheels. To study Caster, we look at the car from the side. Caster is the angle between the center line through the spindle (steering knuckle) pivot point and a perpendicular line on the road.

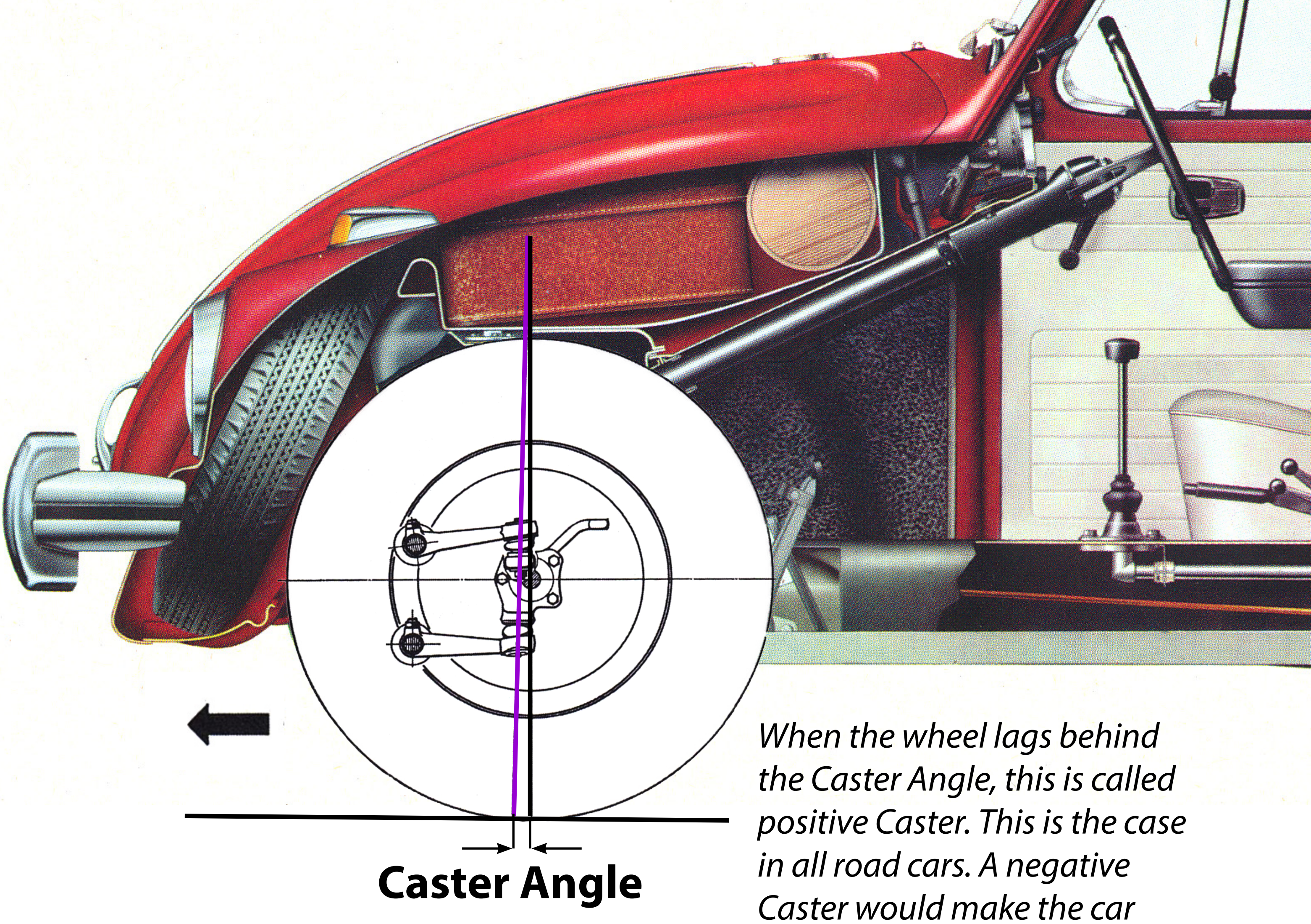
We use the drawing of a front suspension with leaf springs, this is the most classic setup on our classic Volkswagen. This is the post-1965 version with ball joints (knuckleballs). Take a line that runs through the steering rotation axle (purple line). This is the axle that the front wheels will rotate around while steering.



Caster and Toe

In this case, the purple line runs through the center of the upper and lower ball joints. The black line on the drawing is perpendicular to the road surface. The angle between these two lines is the Caster Angle.

In the drawing below, things become clearer when we show the Caster Angle on a VW. You notice that the wheel is lagging behind on the wheel rotation axle. Where else have we seen that?



When the wheel lags behind the Caster Angle, this is called positive Caster. This is the case in all road cars. A negative Caster would make the car uncontrollable.

#76 Front and rear axle

An office chair, shopping cart or a table cart (pictured below) owe their convenient handling to Caster, which is obtained by shifting the steering pin. Shown below is a table cart, the steering wheels will always try to follow the direction of travel. This behavior is due to the position of the wheel. Without the Caster angle, this cart would become completely unmanageable.

In a road car, you will always see positive Caster. Positive Caster provides the self-centering effect, which provides your car's straight-line stability. Just like the front wheels of your shopping cart. Positive Caster gives directional stability to the car because the wheels tend to always return to the straight-ahead position while driving.

Caster Angle

In this table cart, the steering wheels are positioned at the rear, the tangent to the ground of the line through the wheel axle is now behind the wheel, just the opposite of our VW with the steering wheels at the front.

Caster and Toe

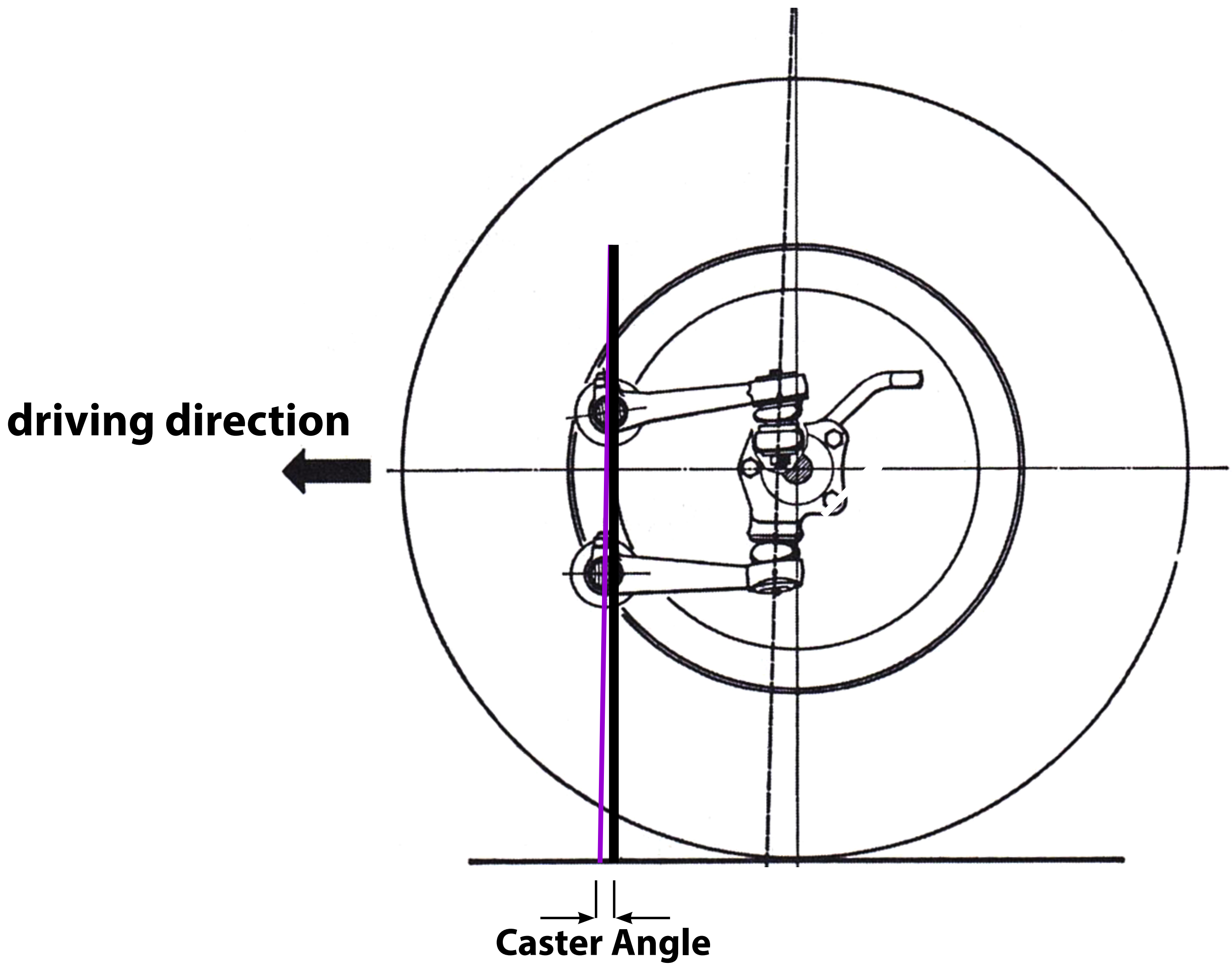
Similar to a bicycle or motorcycle where the fork is tilted (photo below). You may remember, you used to go crazy with your bike, and turn the handlebars 180°, the Caster Angle went from positive to negative. Very difficult to ride, uncontrollable. But when you are young you have to find out where the "line" is.

Also in the example of the motorcycle below, the contact area of the front tire is behind the axle around which the wheel tilts. This gives a motorcycle the necessary stability when steering. You can let go of the handlebars on this bike, even at 120 km/h (we obviously do not recommend this on public roads), and it just keeps going nice and straight. You can see that on a motorcycle the Caster Angle is much larger than on a car.

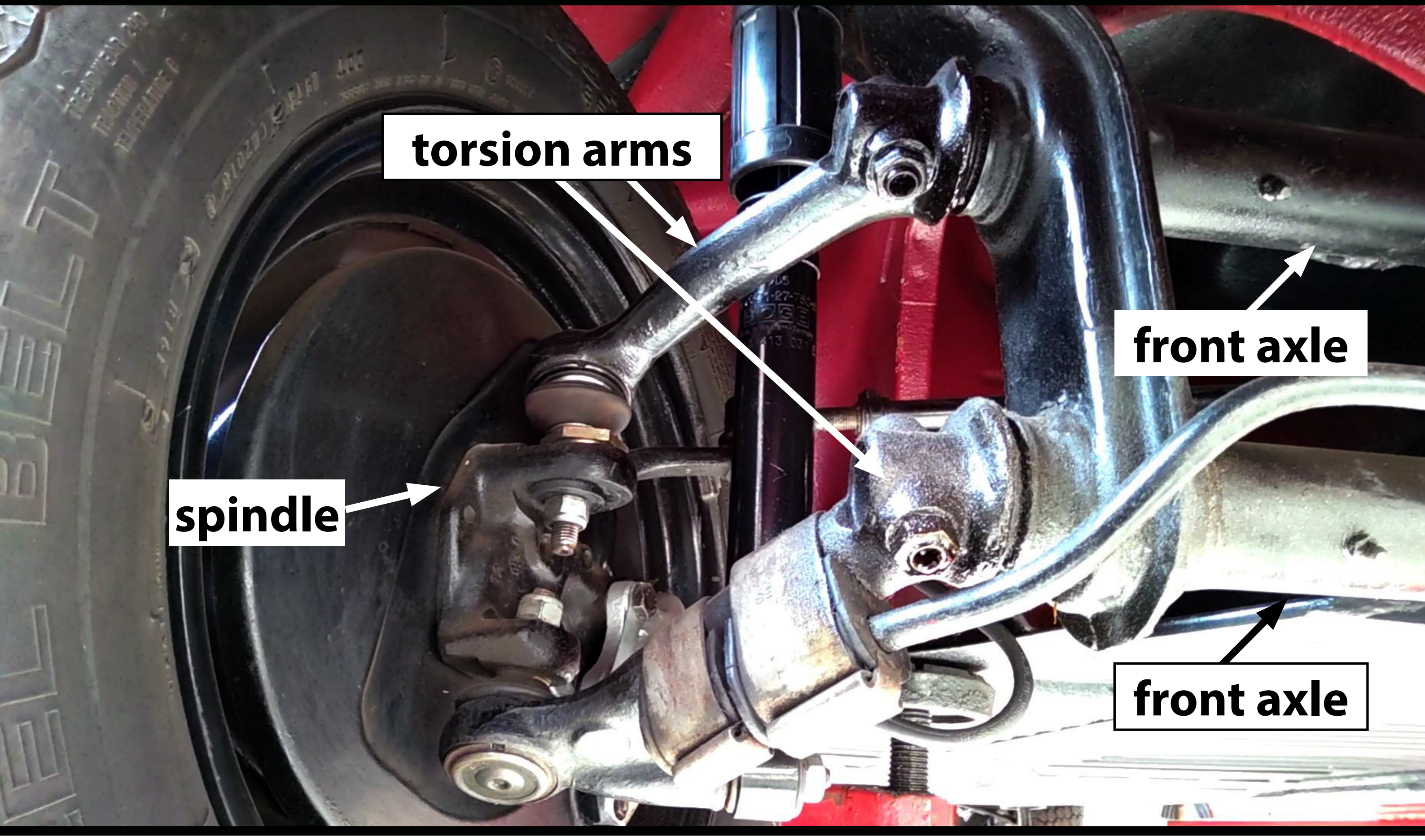
#76 Front and rear axle

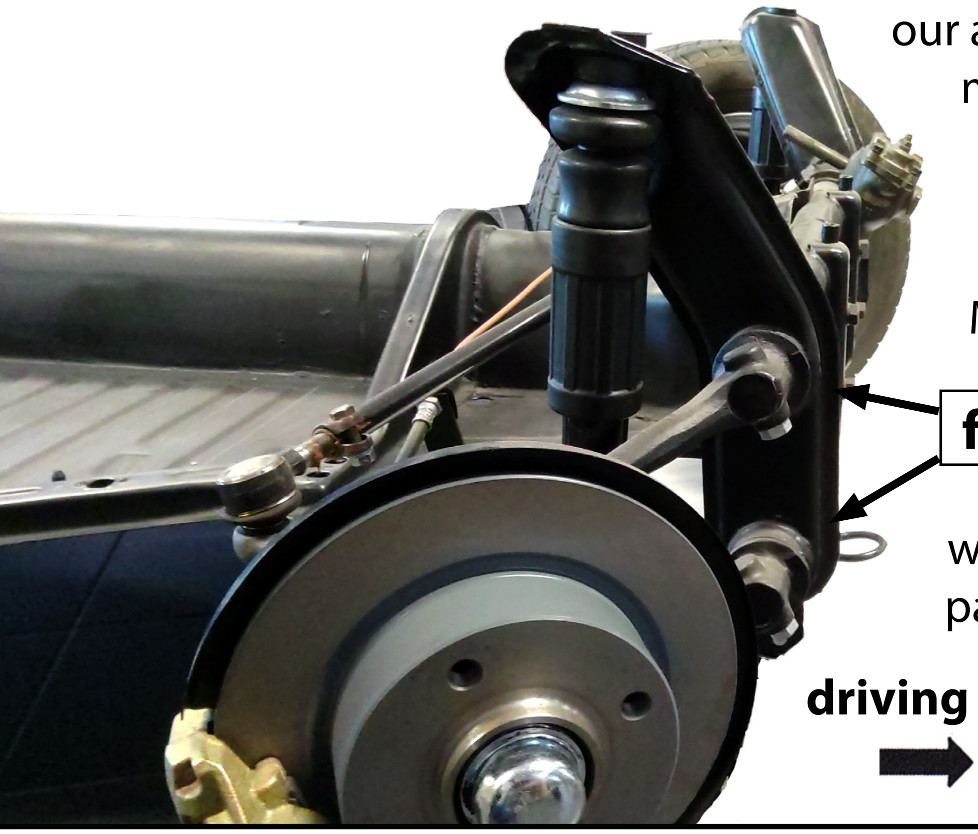
In front suspension, the position of the tubes, which contain the torsion leaves, also plays a role in determining the overall Caster Angle. The two axle tubes also have a tilt (Caster). It is the sum of the angle of the spindle ball joints (or the link pins for pre-1965 models) and of the torsion arms that will determine the overall Caster Angle. In the photos on the next page, we show the front axle.

The Caster Angle is difficult to show in these photos, the angle is very small, barely 2 to 3°. Adjustment is not possible, but the ball joints, the torsion arms or the front axle may have been damaged by a severe shock or by a collision. This will change the Caster Angle, which will affect the steering behavior of the car. Replacing the damaged parts is the only option.



Caster and Toe



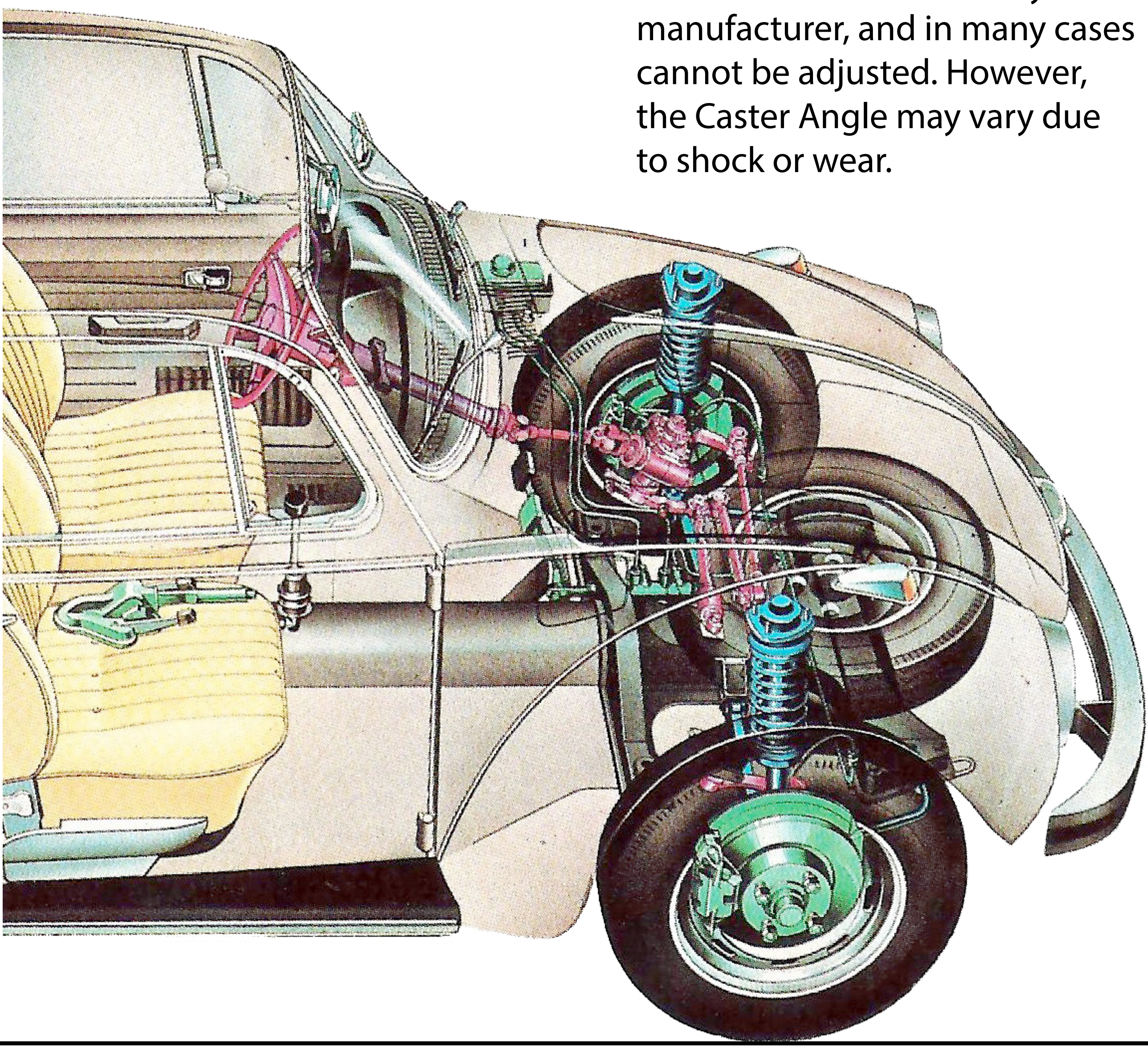


This is the classic front axle of our air-cooled VW with its two metal tubes containing torsion leave blades. Later models were equipped with a MacPherson, even then there is a Caster Angle, which we show on the following pages.

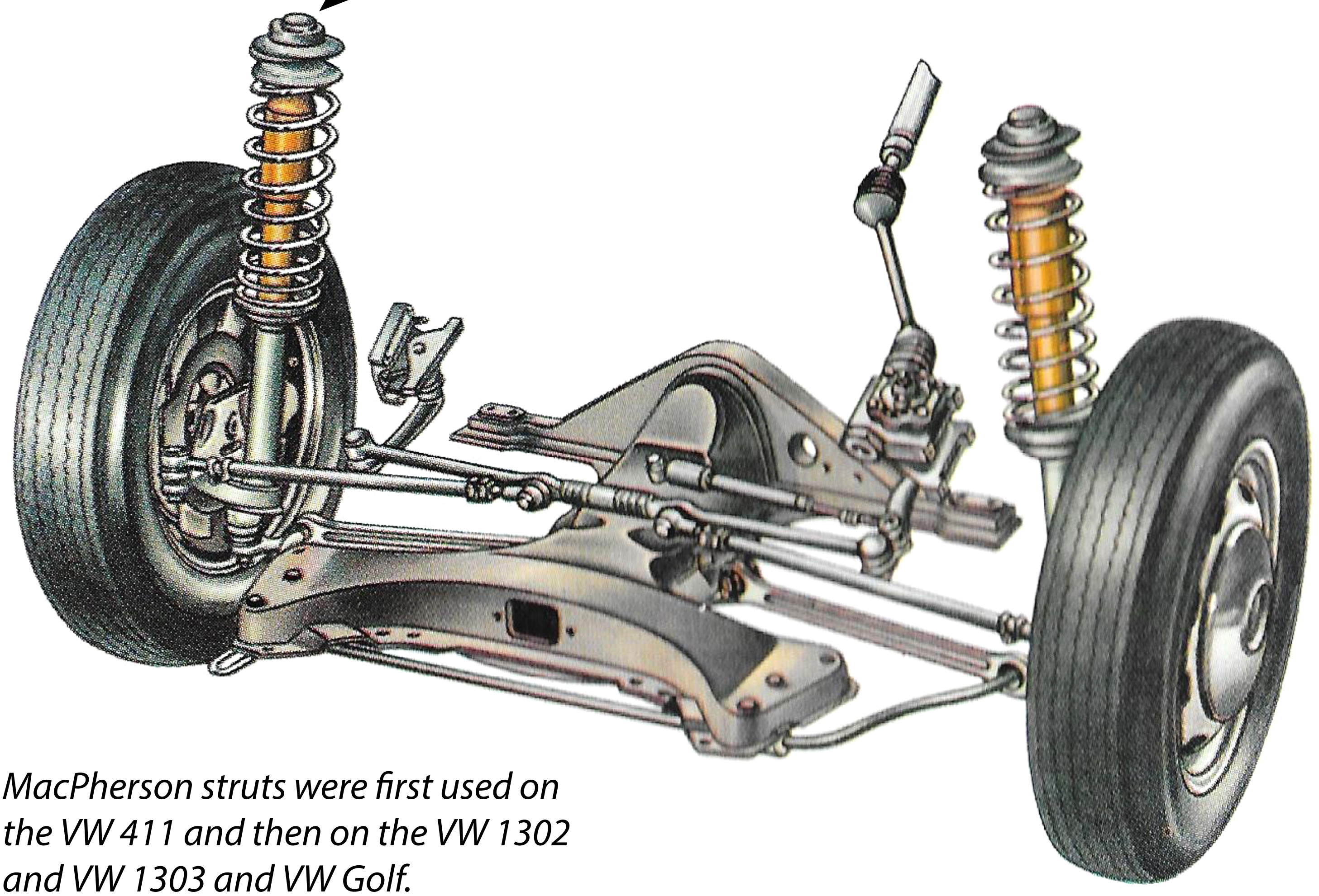
#76 Front and rear axle

The younger VW models used the MacPherson strut (see edition 16 and edition 17) instead of torsion with torsion leaves. Here, the Caster Angle is determined by the tilt of the strut, as that is the axis around which the wheel rotates.

The upper (photo on next page) and lower mounts of the MacPherson strut will determine how much Caster the front wheels have. The upper mount will be more rearward, to give the wheels positive Caster. The value is determined by the manufacturer, and in many cases cannot be adjusted. However, the Caster Angle may vary due to shock or wear.



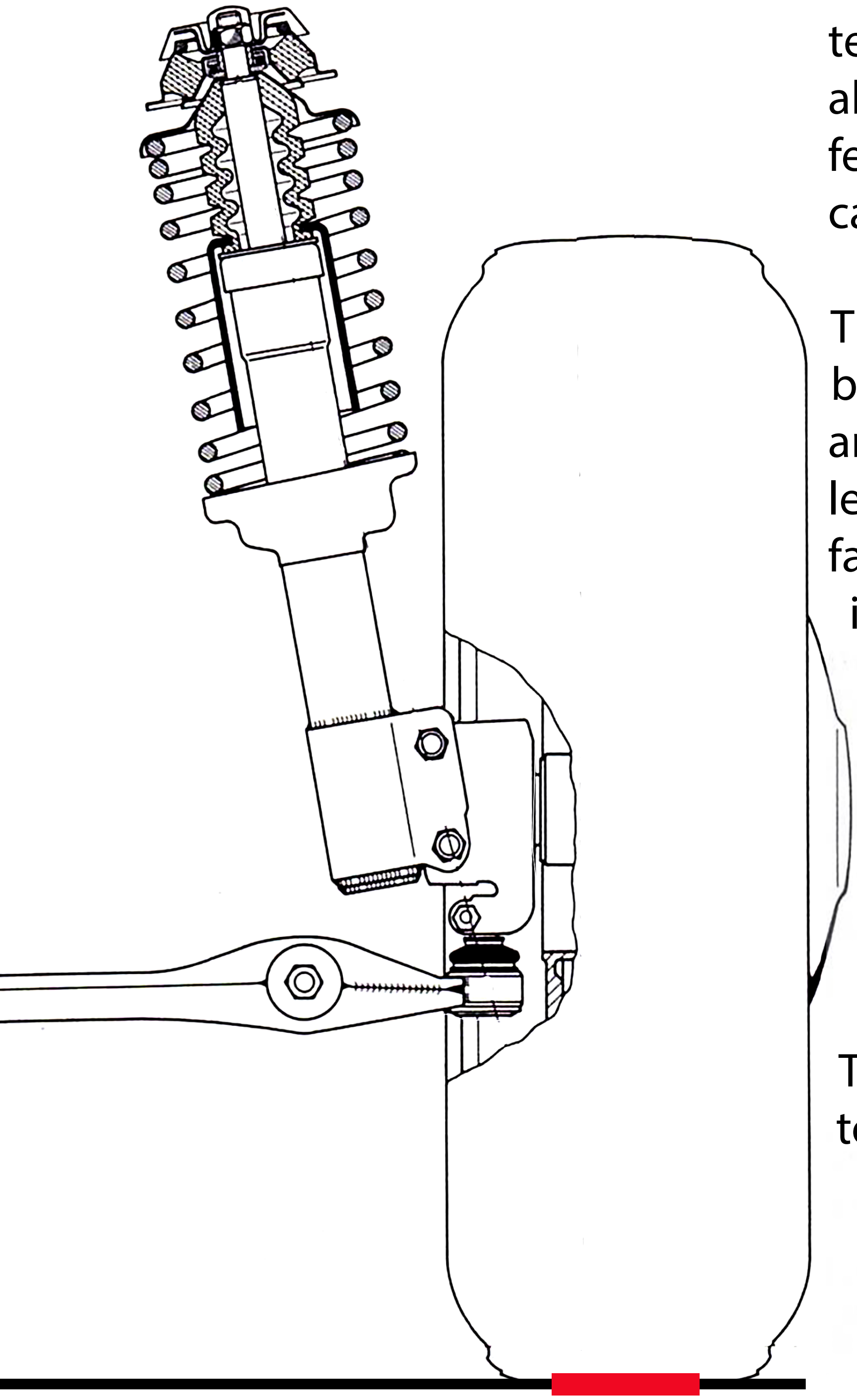
Caster and Toe



MacPherson struts were first used on the VW 411 and then on the VW 1302 and VW 1303 and VW Golf.

#76 Front and rear axle

Now that we know what Caster Angle is, what are the advantages of using a positive Caster?



contact patch

Directional stability

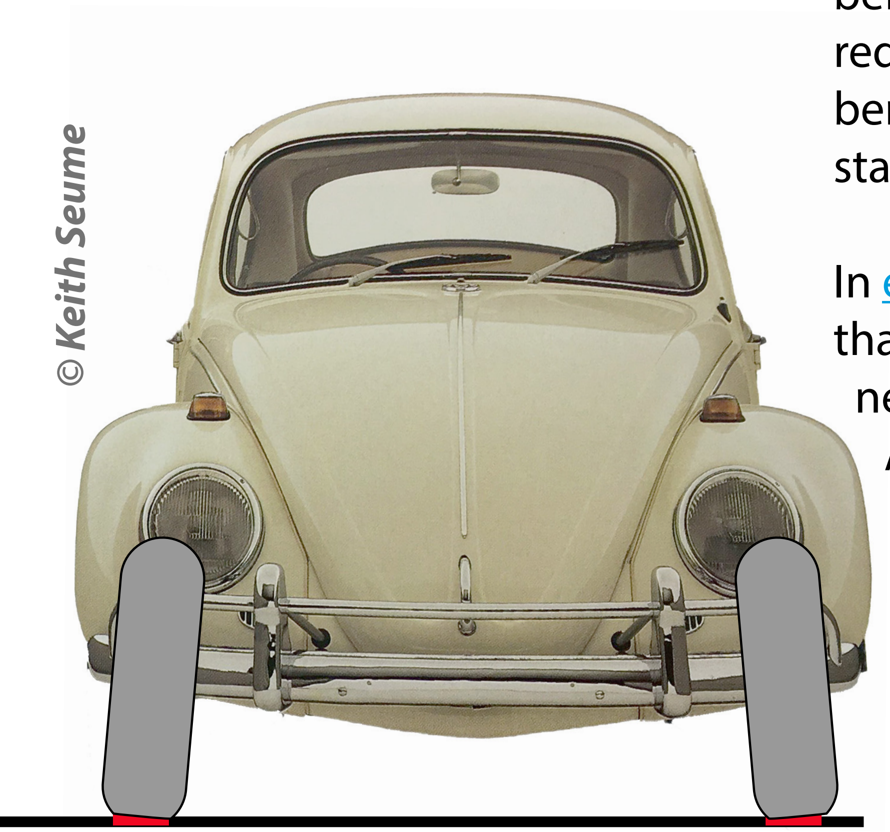
Well, we have already talked at length about directional stability. A positive Caster will ensure that the front wheels will always tend to go back to the straight-ahead position. This is a good feature and helps to make the car easy to drive.

The Caster Angle creates a force between the **contact patch** (red area under the tire on drawing left) of the tire on the road surface and the line of the mounting point, this creates a force in the steering wheel that provides feedback when steering. This force also depends on the mounting point, if it shifts, the feedback in the steering increases or decreases.

Too much Caster will cause you to lose grip on the road.

Caster and Toe

The contact patch with the road is also determined by the width of the tires, the wider the more contact with the road, and by the tire pressure, the less pressure the more contact. Of course, the contact area should not become too small, because then you will lose grip on the road. The shape of the contact patch will also change as the pressure on the tires changes.



dynamic Camber when turning

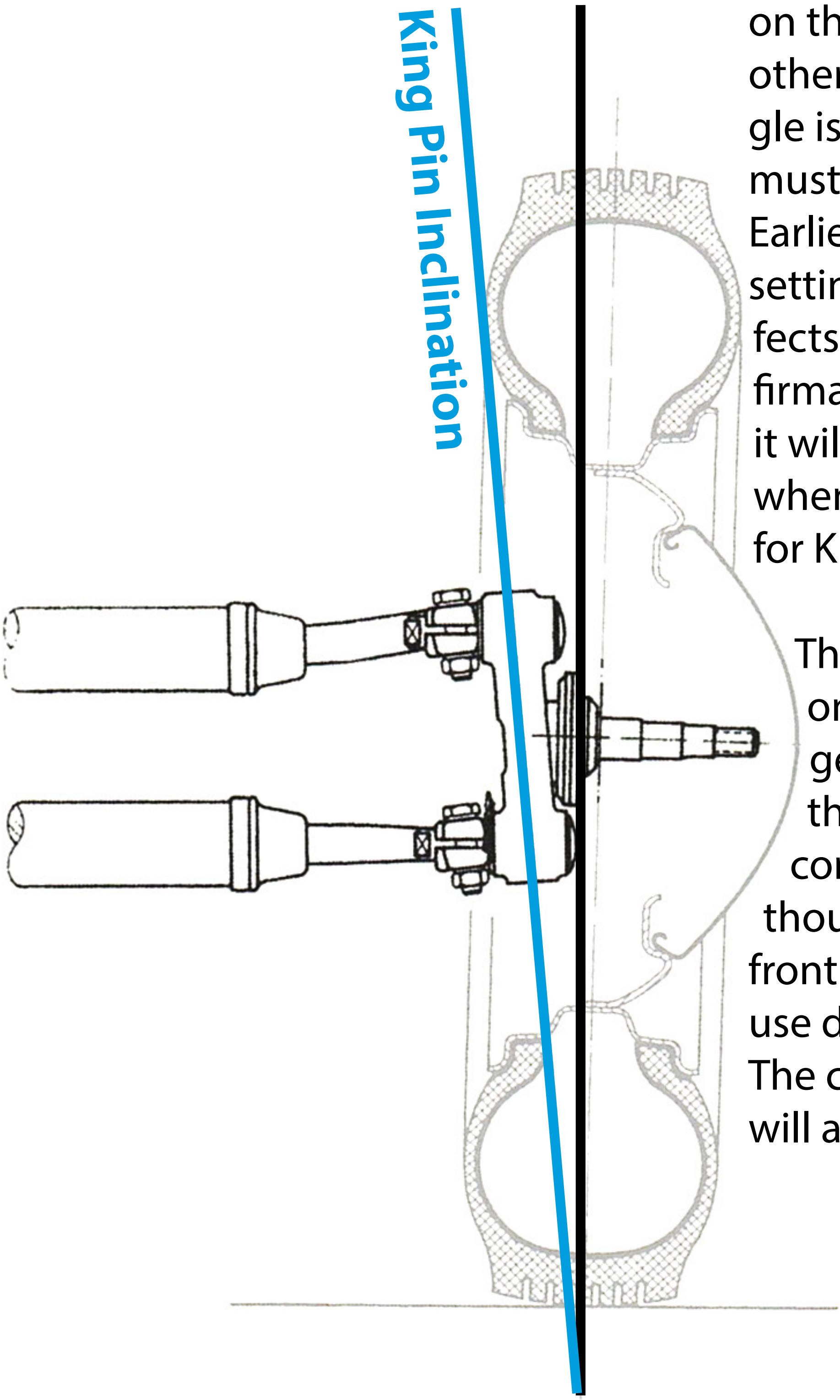
Caster and Camber

Caster will change the Camber Angle when cornering, improve it, to go more stable in the corner. So Caster creates extra Camber (less positive Camber angle) when the steering wheel is turned. This is called dynamic Camber (photo below), because it is created by movement of the steering wheel, and it disappears when the wheels are straight.

This allows for less static Camber when driving straight, thus reducing tire wear. Static Camber is the Camber setting when standing still.

In edition 25 we had explained that King Pin Inclination had a negative effect on the Camber Angle when cornering, Caster thus provides a counter effect and corrects the Camber Angle in the right direction.

#76 Front and rear axle



Caster and King Pin

Caster settings are dependent on the King Ping Inclination, in other words, if the King Pin Angle is adjusted, the Caster Angle must be revisited, and vice versa. Earlier we mentioned that one setting of wheel geometry affects another, this is the confirmation. If you adjust Caster, it will affect the Camber Angle when turning. The same goes for King Pin and Caster Angle.

These settings are fixed data on a factory original Volkswagen, they are determined by the shape of the suspension components. They can change though when you fit a narrower front axle, lower the suspension, use different shock absorbers. The choice of rim size and tires will also affect the geometry.

Caster and Toe

Caster and rear wheels

Just as the King Pin Inclination can affect the Caster Angle, the position of the rear torsion bars will confound the adjustment of axle tilt or Caster. Lowering the rear end, or uneven rear height left and right, will be felt in the handling of the front wheels.

Lift effect

A positive Caster Angle also creates a lifting effect when the wheels are turned. The front inner wheel goes up and the front outer wheel goes down. This causes a lift up effect that puts more mass on the rear outer wheel when cornering. This can create a positive cornering effect because it helps the car turn when entering the corner. However, too much Caster can lead to oversteer due to the lift effect.

Uneven roads

Not enough Caster will increase the effect of lateral forces, such as when driving into a pit or driving on uneven road surfaces. The car is pulled along with every unevenness of the asphalt and becomes difficult to steer, comfort is greatly reduced.

Caster Angle adjustment

Caster Angle does not exceed 2° to 3° in road cars. The 1963 VW manual recommends 2° +/- 15' for the Volkswagen Beetle (15' equals 15/60 decimal, so 2.25°). That is really not much and cannot be adjusted without special tools. And yet this setting will make a world of difference in terms of the car's handling.

In the next edition of this series, we will discuss the adjustment of wheel geometry.

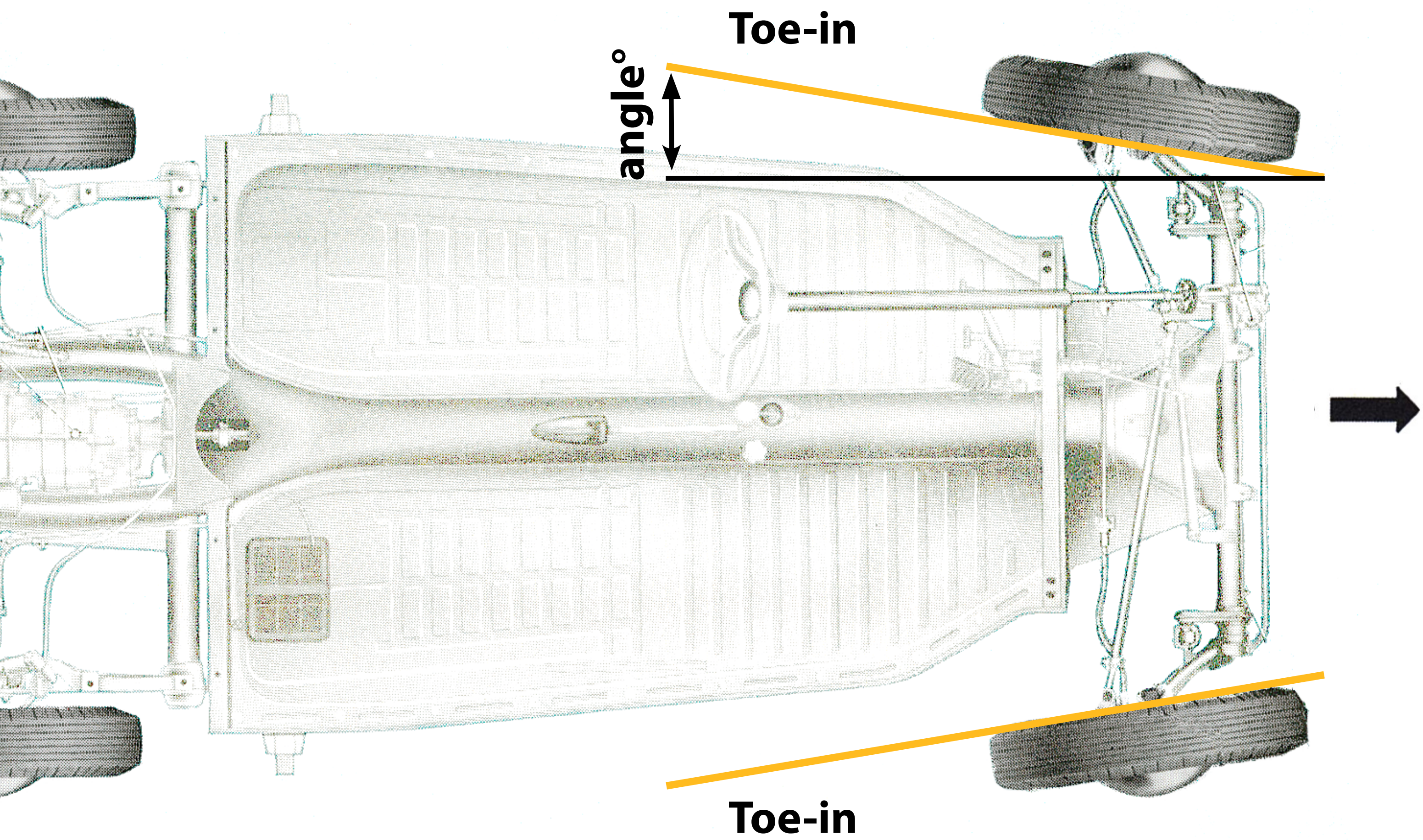
Toe-in and Toe-out

Toe is a setting that is important for both the front wheels and the rear wheels. We'll start with the front wheels.

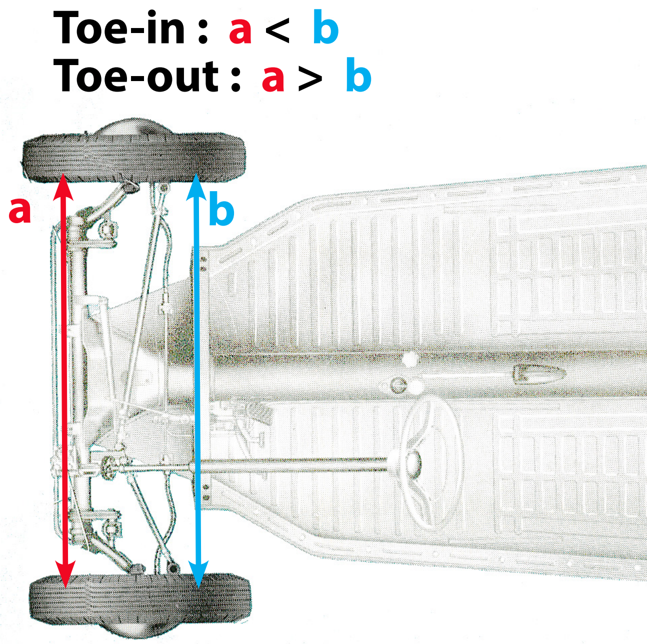
Toe is related to the direction of the wheels. We illustrate this with the drawing below of a Volkswagen Beetle chassis as seen from the top.

Toe is the most sensitive setting of all wheel geometry settings.

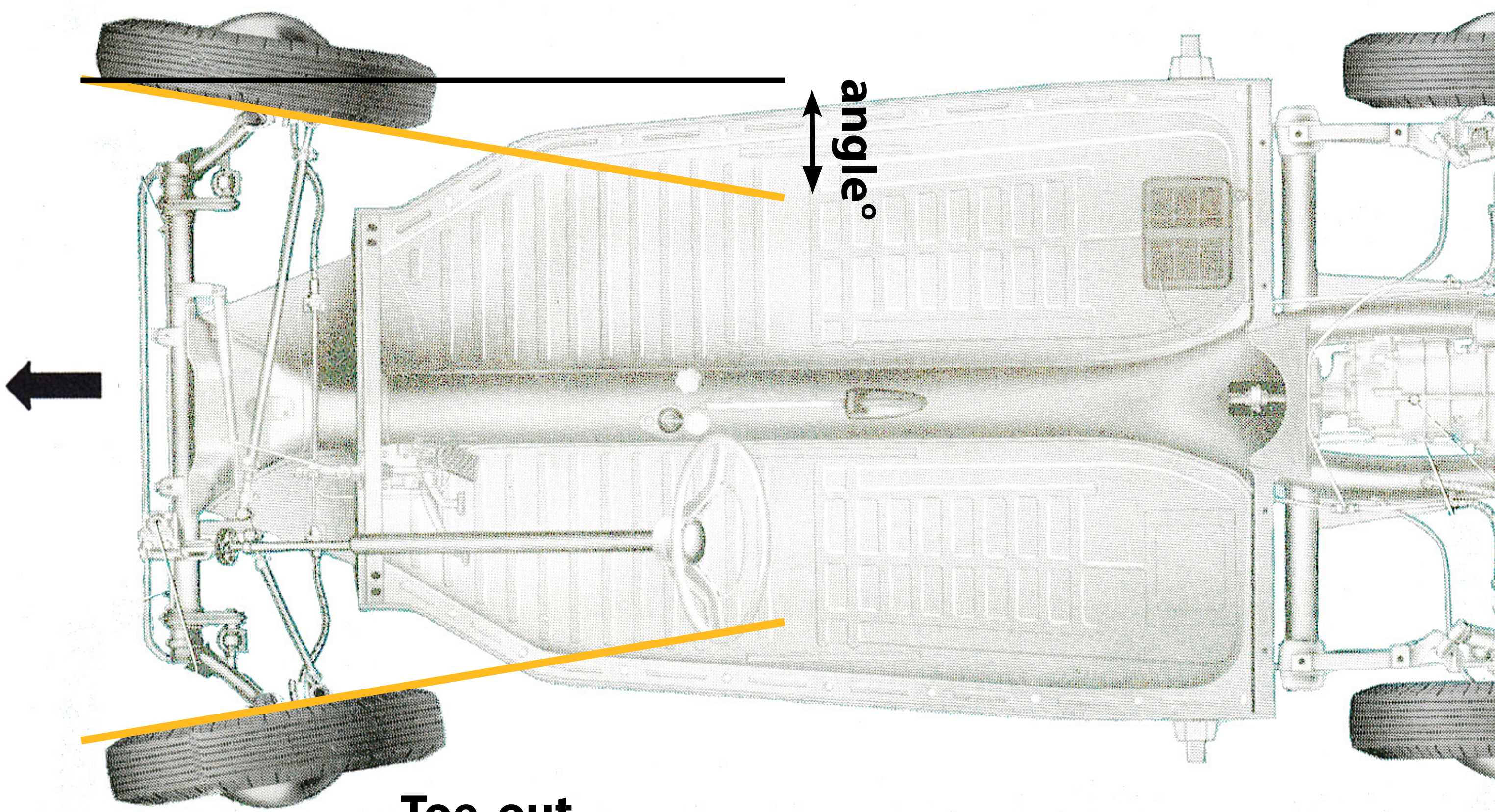
When the wheels point inward, as in the drawing below, we speak of Toe-in or positive Toe. In the drawing on the next page, we show front wheels with Toe-out or negative Toe.



Caster and Toe



Again, the drawings are very exaggerated to make it clearer. In practice, we are talking about a few tenths of a degree or barely 2 to 4 mm between the front of the rims (red arrows on the drawing on the right) and the rear (blue arrows). This is barely visible to the naked eye. Toe is expressed in degrees (see drawing below) or in millimeters as in the drawing above.



#76 Front and rear axle

Now, why is a limited amount of Toe-in on the front wheels necessary on our classic VW?

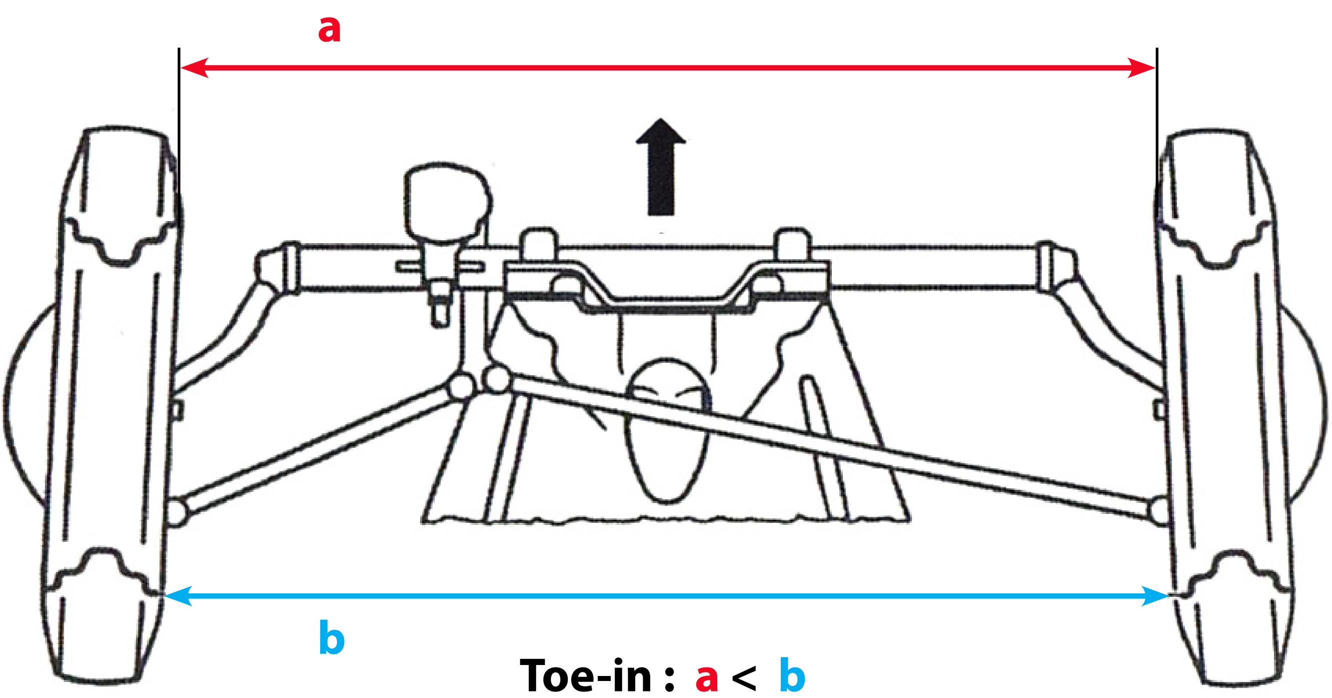
Due to the positive Camber setting (see edition 25) combined with the resistance of the road surface, and play in the wheel bearings and steering components, the front wheels are pushed outward (Toe-out).

In a rear-wheel-drive car, the front wheels are pushed outward and must be corrected with Toe-in.

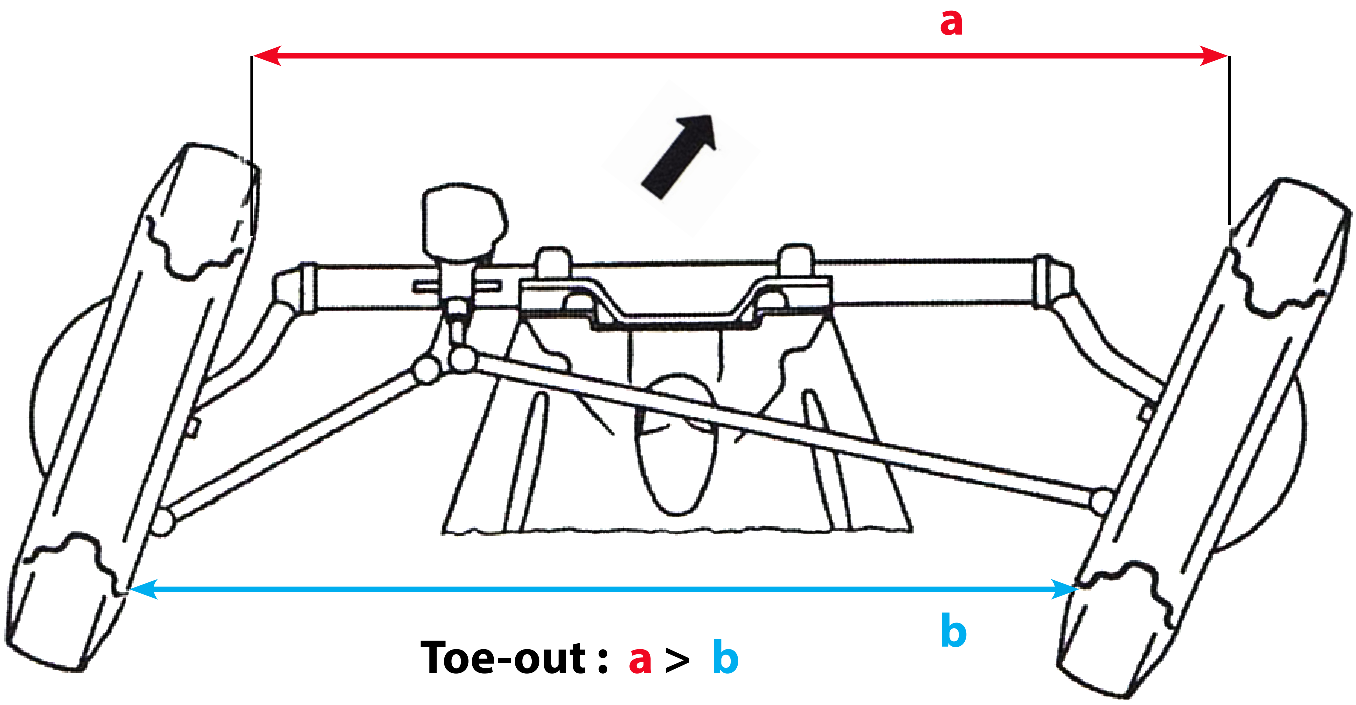
With a front-wheel-drive car it is the opposite, the front wheels are pushed inward and must be corrected with extra Toe-out.

To compensate for this effect, we give the front wheels slight Toe-in. Below we show how Toe-in is measured on the front axle. Against the rim flange at the front and at the rear.

When the red line is shorter than the blue line, there is Toe-in. When the car drives straight, Toe-in ensures that the wheels are still parallel.



Caster and Toe



The drawing above shows the situation when the car takes a turn. The inner wheel has a smaller turning radius than the outer wheel, so the inner wheel will have to turn more. Due to the forces exerted on the wheels, the tracking changes (Toe) from neutral (or slightly Toe-in) in a straight line to Toe-out when the wheel is turned.

If the ball joints or link pins are misaligned or distorted, or there is too much play on the wheel bearings or steering components, then, because of the misalignment, the tires will scrape across the road instead of rolling cleanly, which will promote tire wear.

#76 Front and rear axle

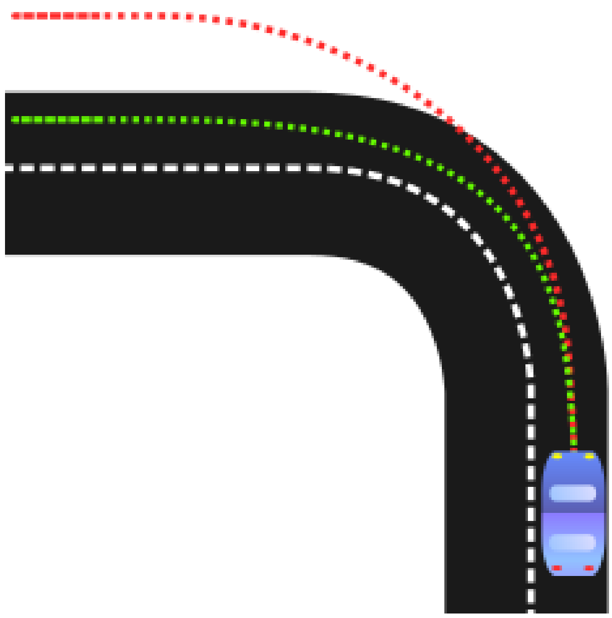
If you were to set a lot of Toe-out, the front wheels would have the ideal position when turning. The inside wheel then naturally follows a smaller radius than the outside wheel, and the car turns cleanly through corners without the tires rubbing on the road surface. But too much Toe-out leads to a very sensitive steering wheel, which reacts at the slightest twist and makes the car change course. It becomes very difficult to drive straight ahead without hard work.

Toe-in is therefore a better choice; it promotes straight-line stability, and dampens all road irregularities to improve steering comfort.

With front-wheel-drive cars it is a bit different, these tend to understeer (see drawing on the right) in the corners, Toe-out gives some extra oversteer to compensate for that effect.

The Toe-in setting is calculated by engineers so that, under normal conditions, Toe-in is practically zero. Toe-in affects the car's behavior when entering a corner, tire wear and straight-line stability.

Understeer occurs when the maximum grip of the front tires is exceeded. The effect is that the car tends to make a fainter turn (red dashed line) than the driver would expect from the steering angle. The car slides, as it were, over the front wheels to the outside of the corner.



© wikipedia.org

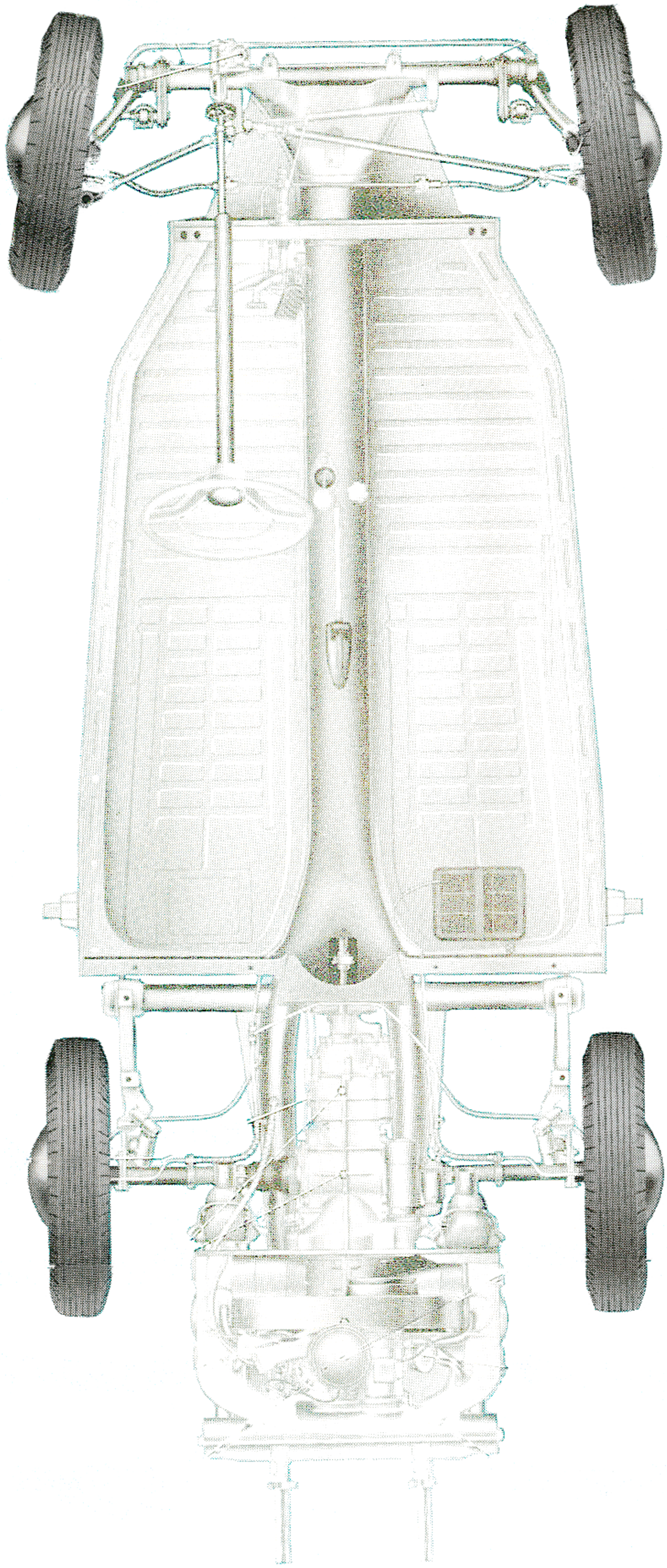
Caster and Toe

What is the effect of misaligned Toe-in or misalignment Toe-out? Misalignment will have an effect on the handling of the car, but most so on tire wear.

Toe-in: Too much Toe-in will cause the extremities of the tires to scrape across the road surface, and wear at those extremities will be seen. A healthy amount of Toe-in has the advantage of increasing straight-line stability.

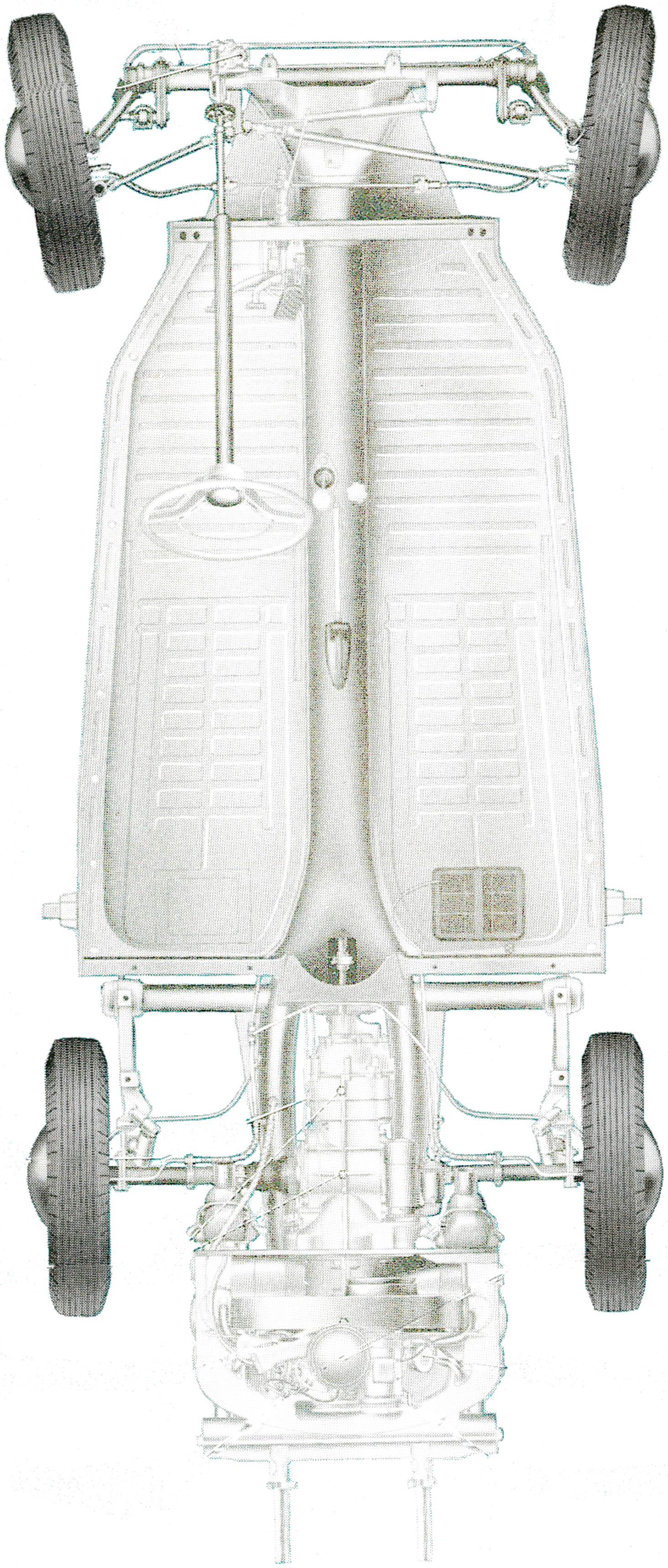
Rear-wheel-drive cars, trucks and SUVs usually get Toe-in because it offers better straight-line stability. The disadvantage is that cornering response is a bit slower. When taking a sharp turn, Toe-in changes to Toe-out to reduce tire scrubbing because the inner wheel passes through a smaller interval than the outer wheel.

Toe-in



#76 Front and rear axle

Toe-out



Toe-out: Increases cornering ability and reduces understeer. When the car begins to turn toward a corner, the inside wheel will make a more aggressive angle. Since its turning radius is smaller than that of the outer wheel, it will easily pull the car in that direction. However, this also reduces stability on straights. But with too much Toe-out, the car will exhibit unstable behavior at high speed and may spin.

Toe-out effects occur mostly in race cars because those vehicles require a very responsive steering system. Whether you are participating in an event at a small local track or drive on the Nürburgring asphalt, many cars will be tuned with some Toe-out.

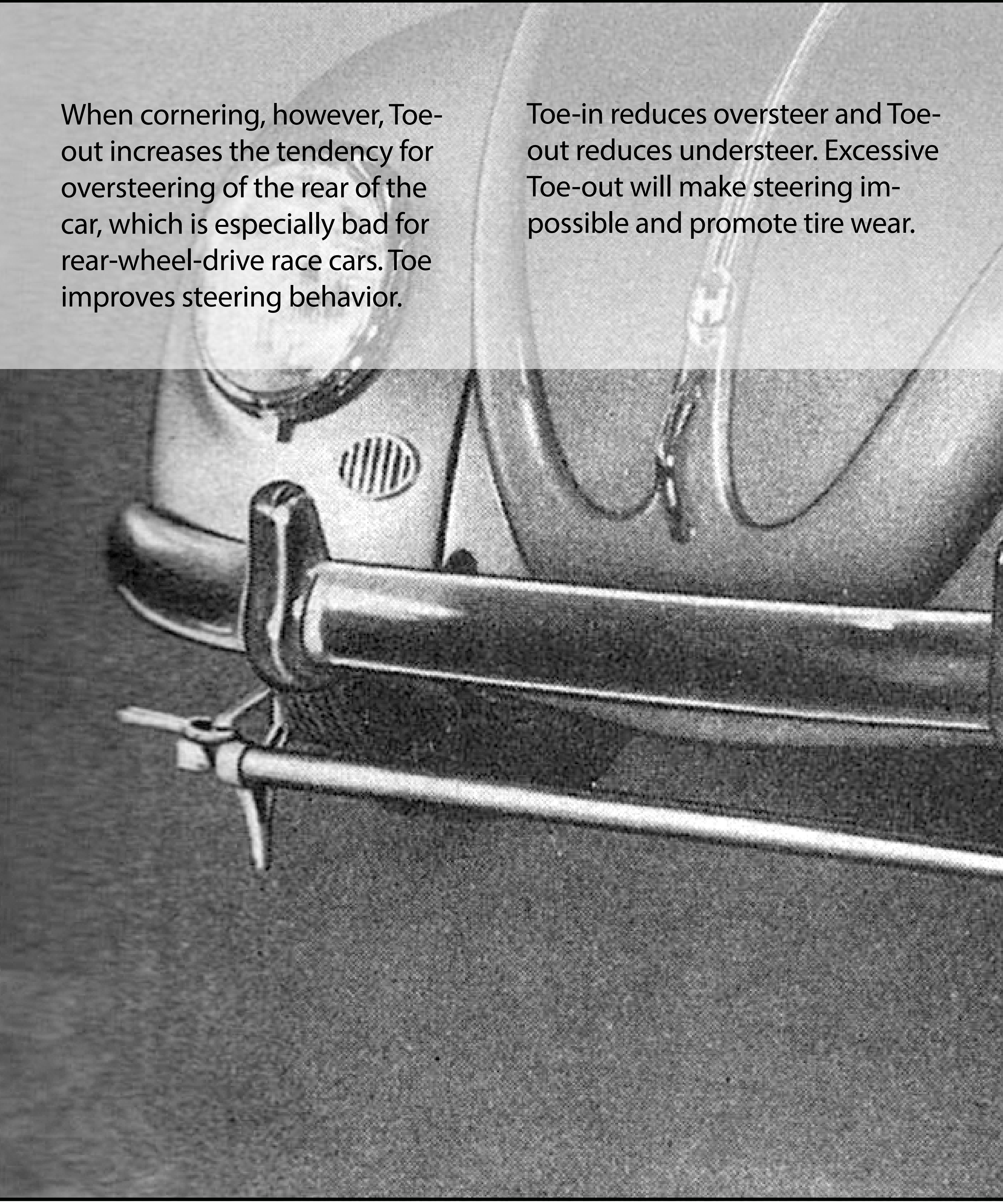
Toe-out on the rear wheels creates a slip angle on the tire to increase rear grip when accelerating.

Caster and Toe

The geometry of our classics was carefully studied by the factory engineers. An ideal adjustment of the wheel geometry for mixed use on the highway and in the city will give minimum tire wear and maximum comfort with the best handling. If racing on the track, the geometry chosen will depend on the track.

If it is a straight ahead sprint, then maximum straight-line stability will be chosen, if there are many tight corners, then controlling understeer and oversteer will become more important. Is it an endurance race, then tire wear becomes a priority.

#76 Front and rear axle

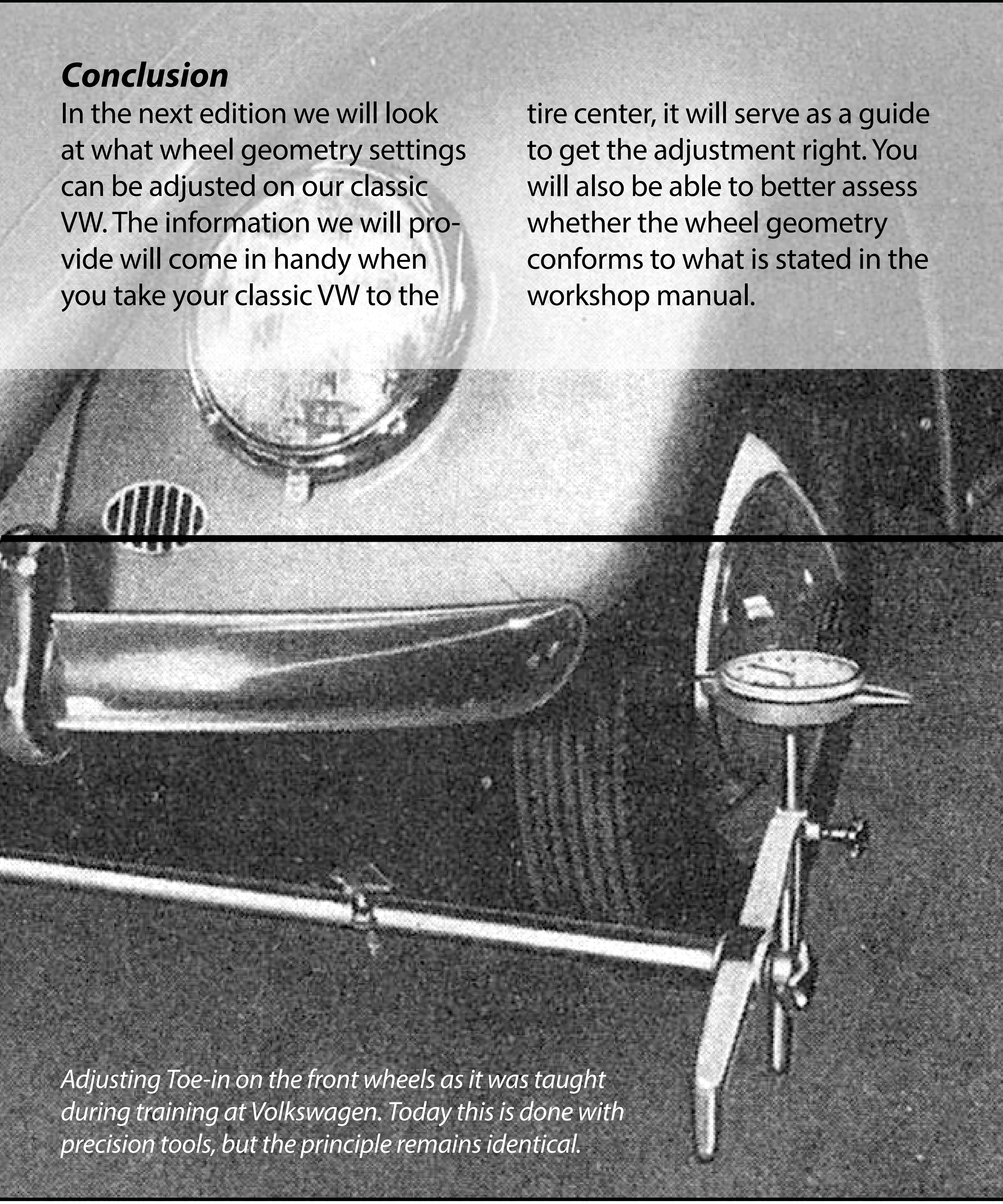


When cornering, however, Toe-out increases the tendency for oversteering of the rear of the car, which is especially bad for rear-wheel-drive race cars. Toe improves steering behavior.

Toe-in reduces oversteer and Toe-out reduces understeer. Excessive Toe-out will make steering impossible and promote tire wear.

Conclusion

In the next edition we will look at what wheel geometry settings can be adjusted on our classic VW. The information we will provide will come in handy when you take your classic VW to the tire center, it will serve as a guide to get the adjustment right. You will also be able to better assess whether the wheel geometry conforms to what is stated in the workshop manual.



Adjusting Toe-in on the front wheels as it was taught during training at Volkswagen. Today this is done with precision tools, but the principle remains identical.

Introduction

In edition 25, we showed how to replace the brake fluid. We did that by flushing the brake lines with new brake fluid, using compressed air. Flushing the brake circuit is recommended after a prescribed number of miles or after two years. If you have just purchased a vintage car, we recommend flushing the brake circuit if no reliable maintenance history is available.

After flushing, your car will have fresh brake fluid, and the brake lines will also have been bled.

Of course, flushing is not always necessary. If you have disconnected a brake hose or brake line, or you have disassembled a brake cylinder or caliper, then bleeding part of the brake circuit is sufficient. This saves brake fluid and it's done faster than complete flushing.

You can, of course, bleed with the tools we showed in edition 25, but you can also do it the old way, with someone pushing the brake pedal for you, following the correct procedure.

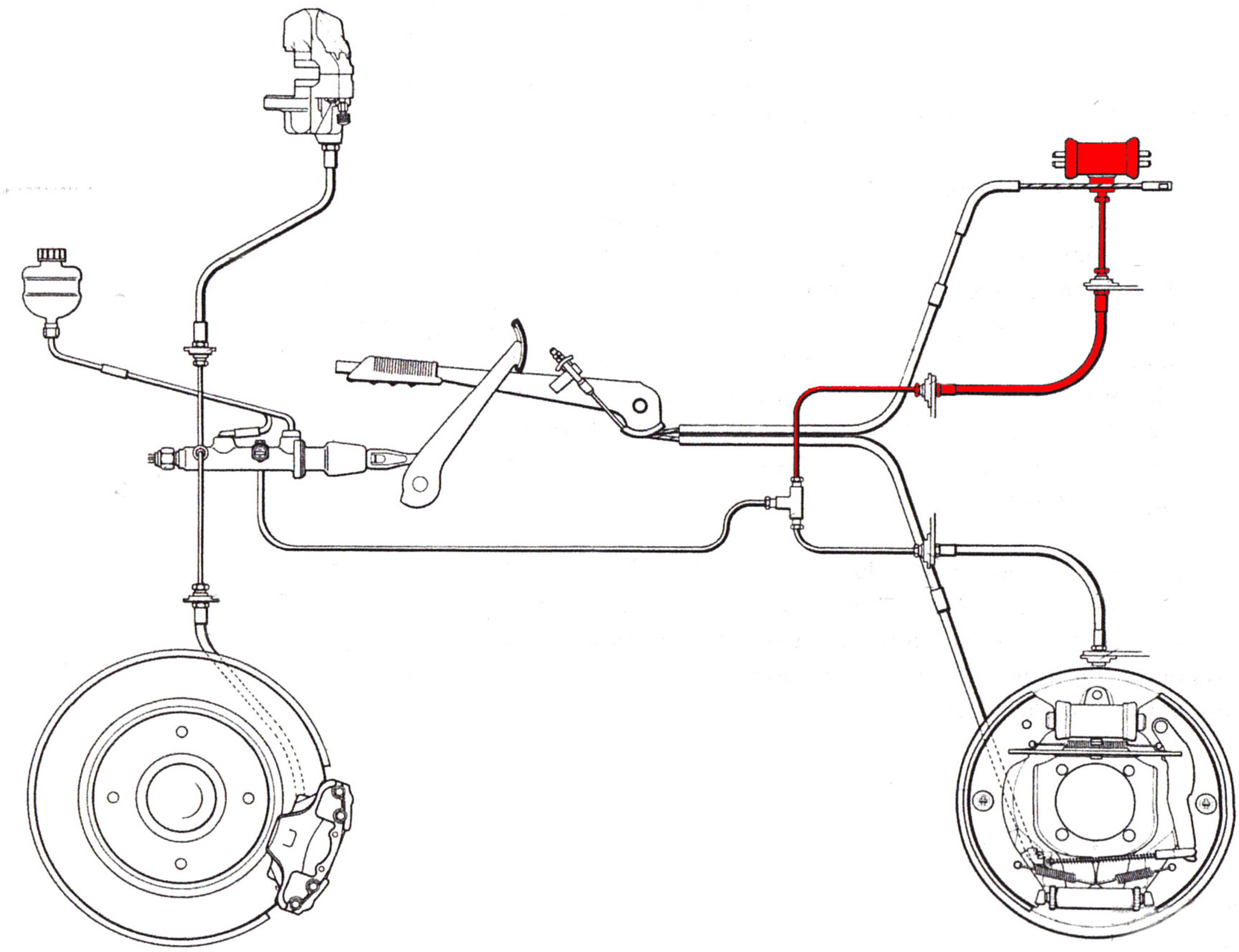
Flushing the entire brake circuit is not recommended with this simple technique.

brake circuit bleeding

Below we show a typical hydraulic brake circuit. In **red** is the drum brake line for the right rear brake. The method we will use here uses the brake pedal to push the brake fluid out, unlike the technique in edition 25 where we sucked the brake fluid out of the brake circuit with a vacuum system.

The method in which we use the brake pedal is a two-person job. It is also only recommended to bleed a part of the brake circuit, not to flush all the lines. It matters little whether it is a drum brake or a disc brake.

To bleed the brakes, all brakes must be properly adjusted, there must be no leaks, and the free play of the brake pedal must be properly adjusted.



Procedure to be followed

1 The first thing to do is to find the brake fluid reservoir, and fill it with DOT3 or DOT4 (see edition 25). While bleeding, the fluid level will drop. If you bleed one brake, then not much brake fluid will be consumed, and this one-time refill is usually sufficient to bleed the line.

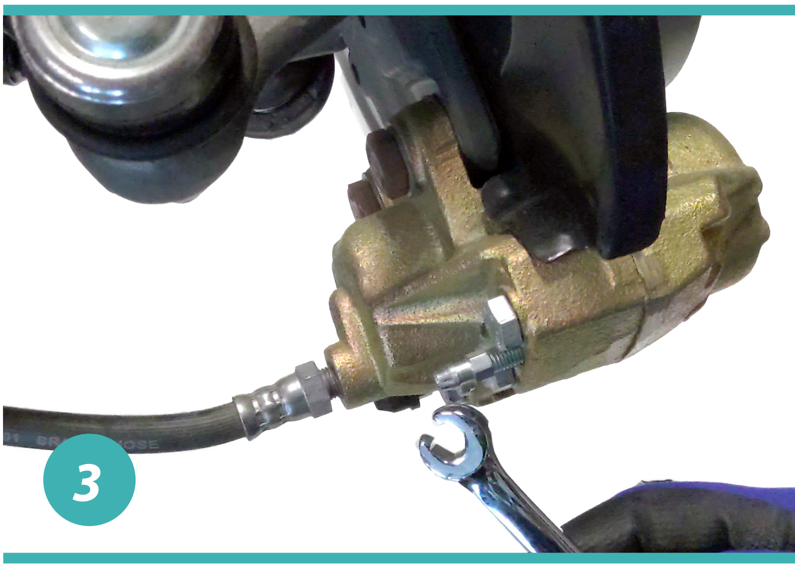
If you want to bleed a larger part of the brake circuit, then a refill container as shown in edition 25 is useful, but then it may also be better to use an air pressure tool, rather than this method.

Protect the paint around the fluid reservoir; brake fluid can be corrosive.

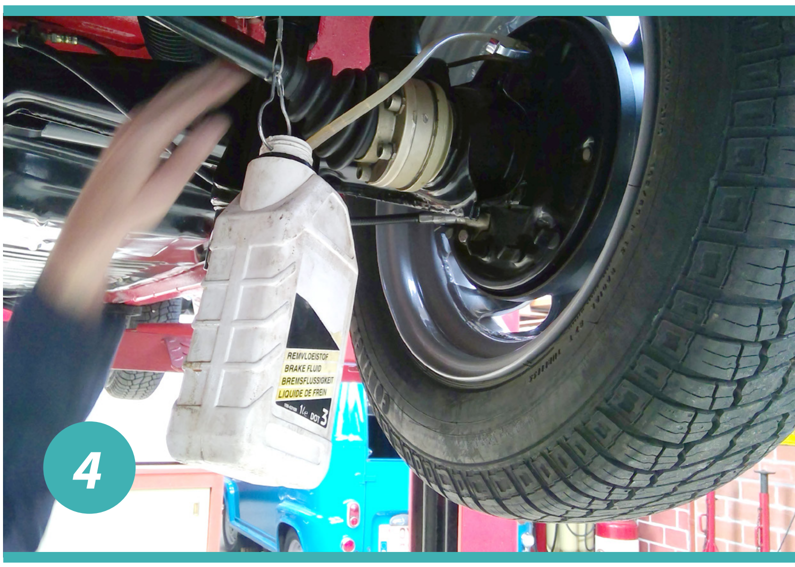
brake circuit bleeding

2 It is more convenient to remove the wheel because everything will be more accessible. Use a decent lifting jack, not the scissor jack that comes with the car. If you have a garage lifting bridge, the wheel can stay on, but few enthusiasts possess this luxury.

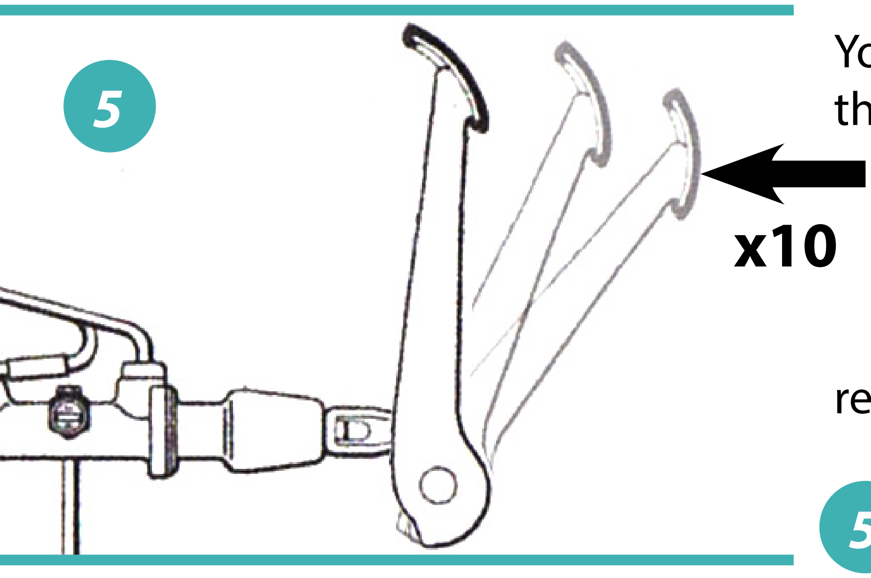
3 Remove the rubber dust cap from the bleed nipple, and place a closed ring wrench (or a semi-closed wrench) on the nipple. The bleed nipple is always located at the top of the caliper (on disc brakes) or wheel brake cylinder (on drum brakes). Air always tends to go to the highest point, which is why the nipple is always at the highest point.

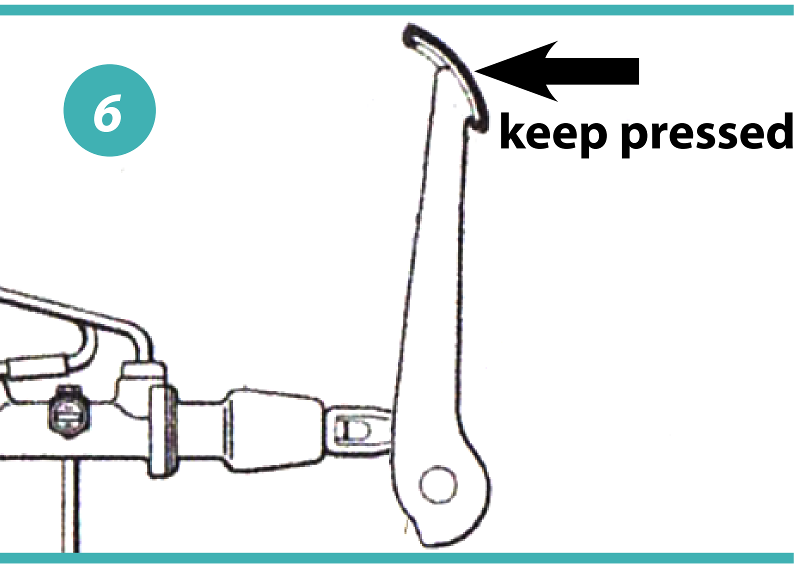


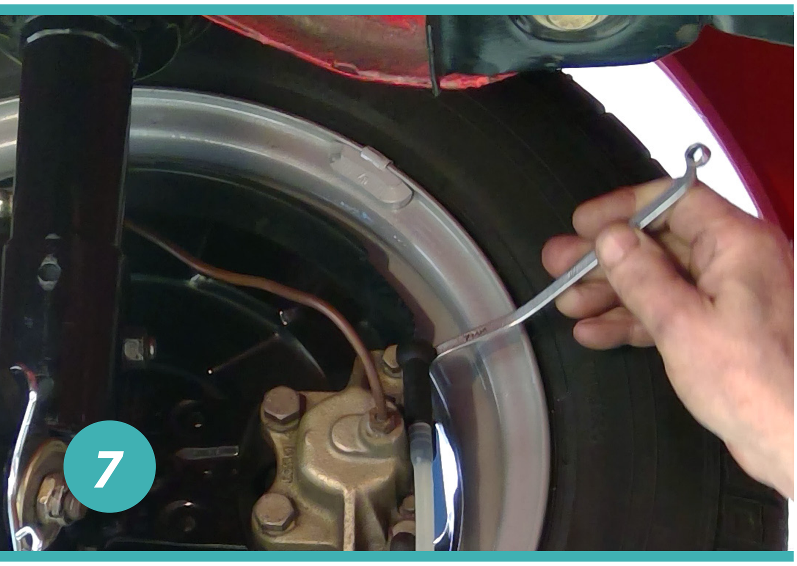
4 Use a clear hose with a collection bottle. We use an empty plastic motor oil bottle, with a convenient hook to attach the bottle to the chassis.



#77 Brakes







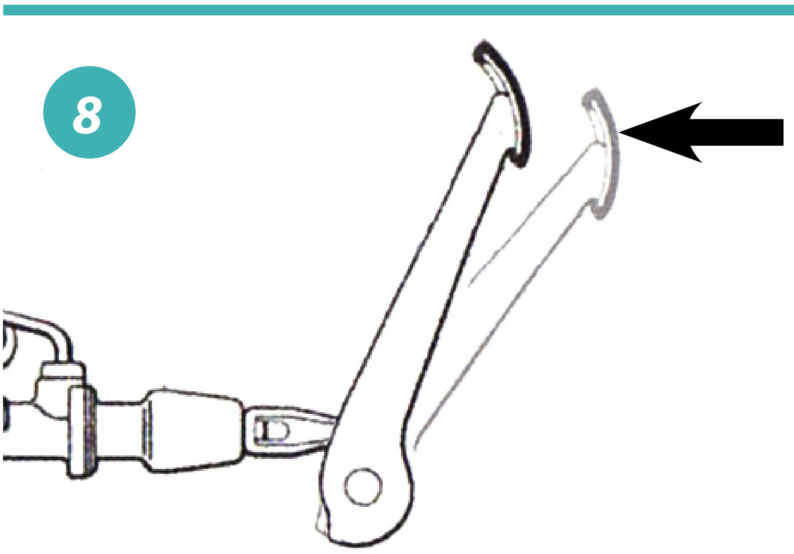
You will quickly understand that this is a two-man job, one person at the bleeder nipple and one person pushing the brake pedal and checking the level of the brake fluid reservoir.

5 With the nipple closed, firmly press and depress the brake pedal several times until you begin to feel back pressure. If there is a lot of air in the brake circuit, it may still feel very spongy, and you may be able to push the brake pedal all the way to the stop.

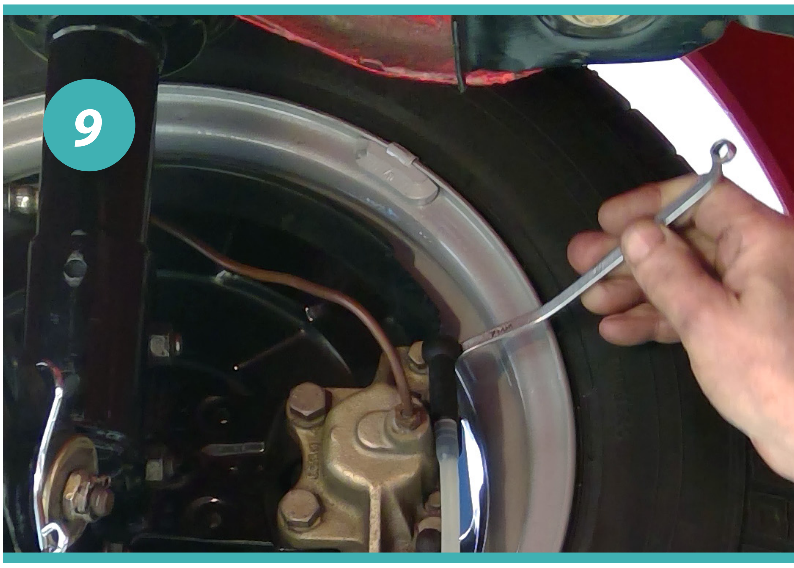
6 After pushing the brake pedal about ten times, press and hold down, keep applying pressure.

7 You open the bleeding nipple a quarter to a half turn at most while the brake pedal is firmly pressed. Some brake fluid with air bubbles should flow through the transparent hose.

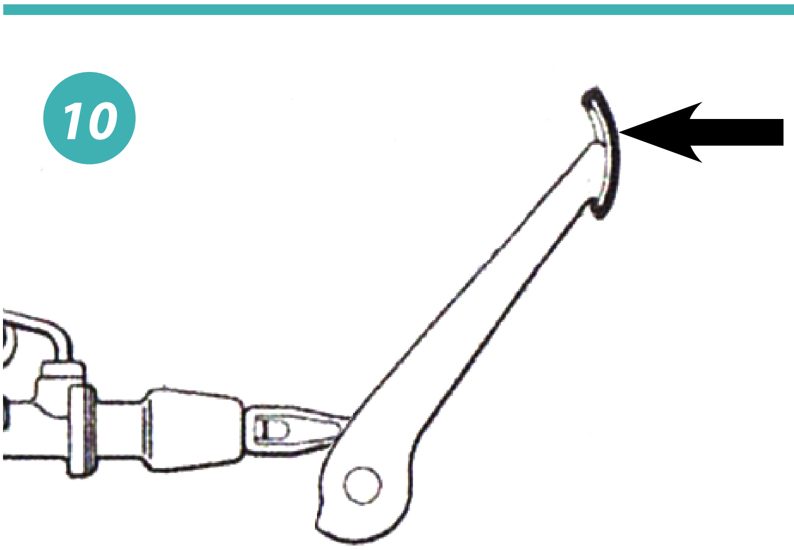
Let the brake fluid flow for a few seconds and close the bleed nipple. Don't forget to check the brake fluid level in the reservoir!



8 With the nipple closed, resume pressing the brake pedal firmly repeatedly, then hold it down. As the brake circuit is bled, the brake pedal will not be able to be pressed as deeply, as we show in drawing 8.



9 While pressure is being performed on the brake pedal, open the nipple again and let brake fluid flow into the collection bottle. You should still see some air bubbles flowing along with brake fluid.



10 Repeat this until no more bubbles can be seen. This will be confirmed by the back pressure on the brake pedal. Normally after a few rounds, the brake pedal should be virtually impossible to press, except for the free play of course.

#77 Brakes

What if things don't go as planned?

What looks like an easy job is the most underrated chore on vintage cars. Only when your vintage car's brake circuit is in perfect condition will bleeding be fairly easy. If not, bleeding can take forever and sometimes never really succeed. We discuss the most common reasons below.

Leaks

Before bleeding the brake circuit, make sure there are no leaks. Check the connections at the brake fluid reservoir, the master cylinder, all connections between the metal lines and rubber hoses, and the connections to the calipers and/or wheel brake cylinders. A small leak will cause brake fluid to drain, but just as bad, it will cause air to be drawn in. Bleeding then becomes an endless chore.

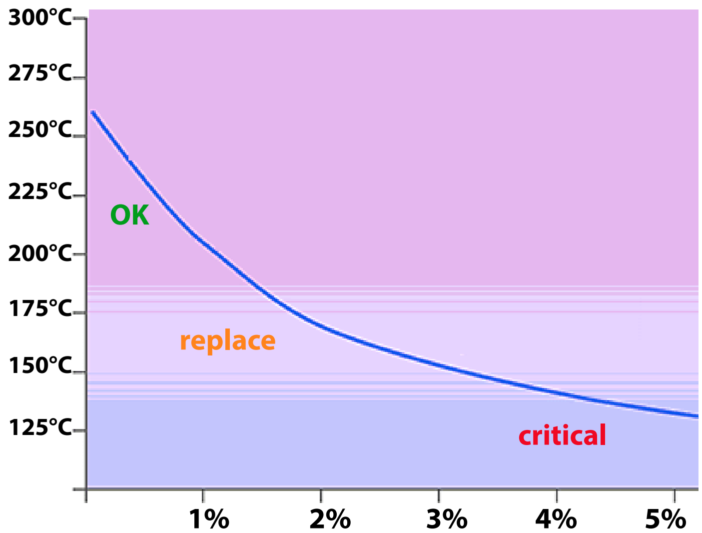
Contaminations

Fluids are not compressible. Brake fluid is designed to boil only at very high temperatures. If the brake fluid is contaminated with remnants of rubber from the brake hoses or metal from the brake lines, or worse water from condensation, the properties of that fluid will change.

Water

Water in the brake fluid will cause the boiling temperature to drop. When the brakes are subjected to heavy loads, air bubbles will form and the brake fluid will compress. As a result, the brake pedal feels soft, and you have to push deeper to get the brakes to apply. So it is possible that the brake circuit is perfectly vented, but with frequent use of the brake pedal, the brake fluid warms up, and the brake pedal feels softer and softer until there is no more braking force to be felt.

Air bubbles in the brake circuit will be felt when you press the brake pedal. If the pedal keeps going down when you apply pressure with your foot, there is probably an air bubble somewhere.



A chart showing the ratio of percentage of water to temperature of DOT3 brake fluid. From 2% water you need to flush the circuit.

Adjusting brakes

Note that if drum brakes are poorly adjusted, it will give a similar soft feel to the brake pedal as if there was air in the system.

Flushing

If the brake pedal continues to feel spongy, even after bleeding the brake circuit several times, it is possible that there is water, or other contaminants, in the brake fluid. Residues of rubber or metal will darken the brake fluid, but you won't be able to see if there is water in the brake fluid, unfortunately.
If the brake fluid released during bleeding is a dark color, you will have to keep pushing on the brake pedal until the brake fluid is transparent. If this is the case with your VW, it is best to flush the brake circuit with fresh brake fluid, as explained in edition 25. Bleeding part of the brake circuit will not give good results. We recommend flushing if you do not know the history of your VW.

#78 Electrical

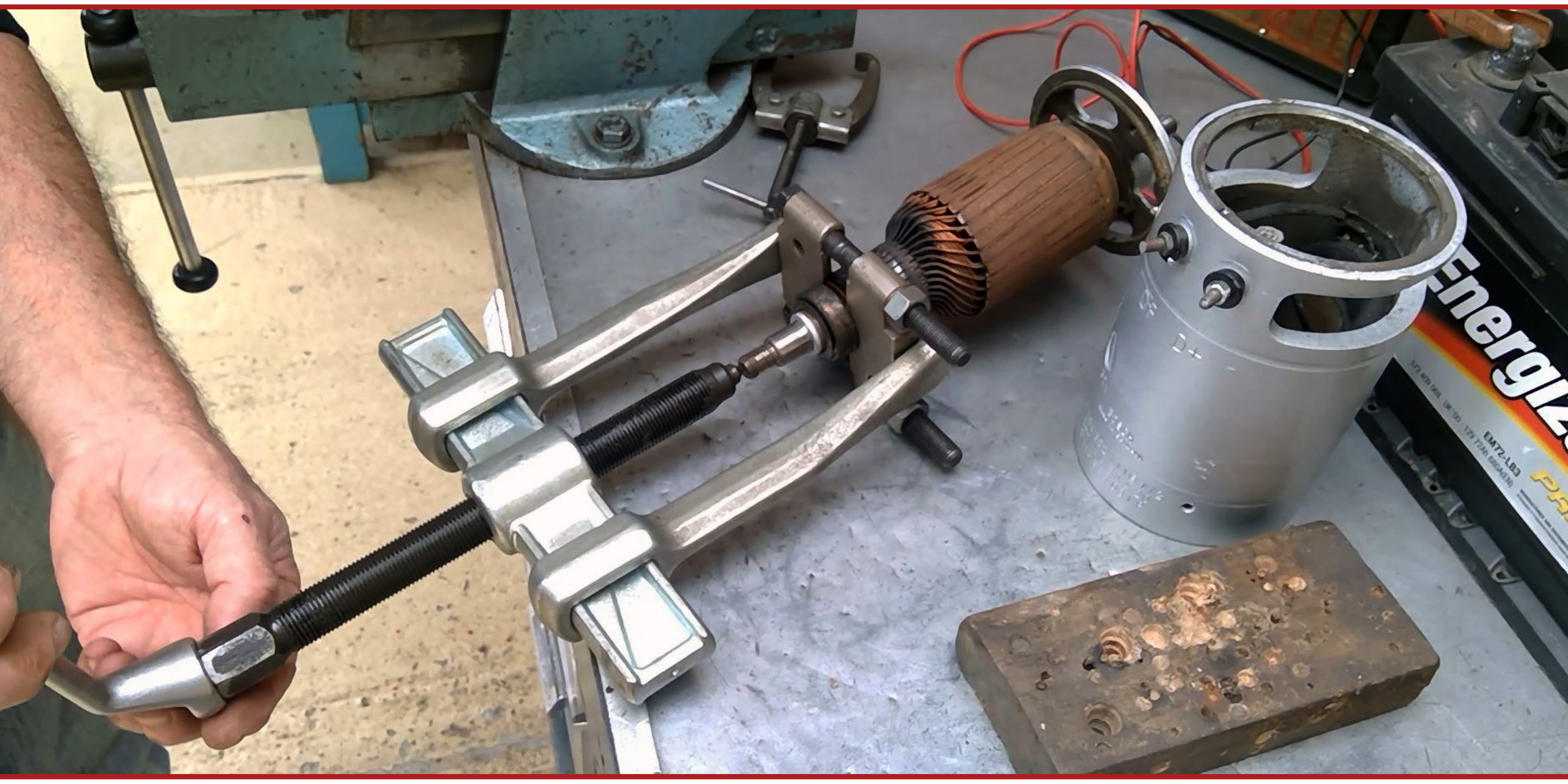
Introduction

A car draws the necessary electrical power from the battery. This current is needed to turn the starter motor, for ignition and to supply all electrical consumers with the necessary power. The battery is an accumulator of electrical energy; the energy used from the battery must be replenished by an electrical generator.

Since the battery is a direct current source (see edition 17), it must also be charged by a direct current source.

And there is the first challenge, all generators produce alternating current (inside). Therefore, various techniques were applied to turn this alternating current into direct current. In this article, we will explain the principles of the generator. Why is this interesting? This is the reaction of most VW enthusiasts.

Photo below: you will be able to distinguish the parts of a dynamo and an alternator at a glance after reading this series.



Kryptic designations on the generator create confusion for the inexperienced VW enthusiast.

This article is written in several parts. In this edition, we will explain the principle operation of the dynamo. In subsequent editions, we will discuss the alternator, as well as the complete overhaul and connection of both the dynamo and the alternator.

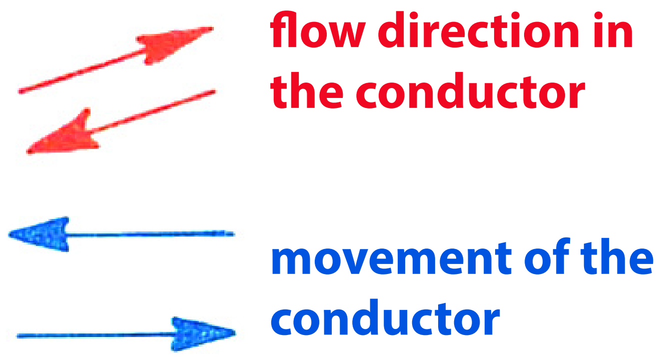
When you have disassembled or overhauled the dynamo or alternator, connecting it is always a bit of a search. You may have noticed these markings on the alternator or on the voltage regulator, B+, D+, DF, D-, ... but you have no idea what they mean. So you start searching and trying. Well, trying is not a real option, you usually don't get a second chance with this type of part.

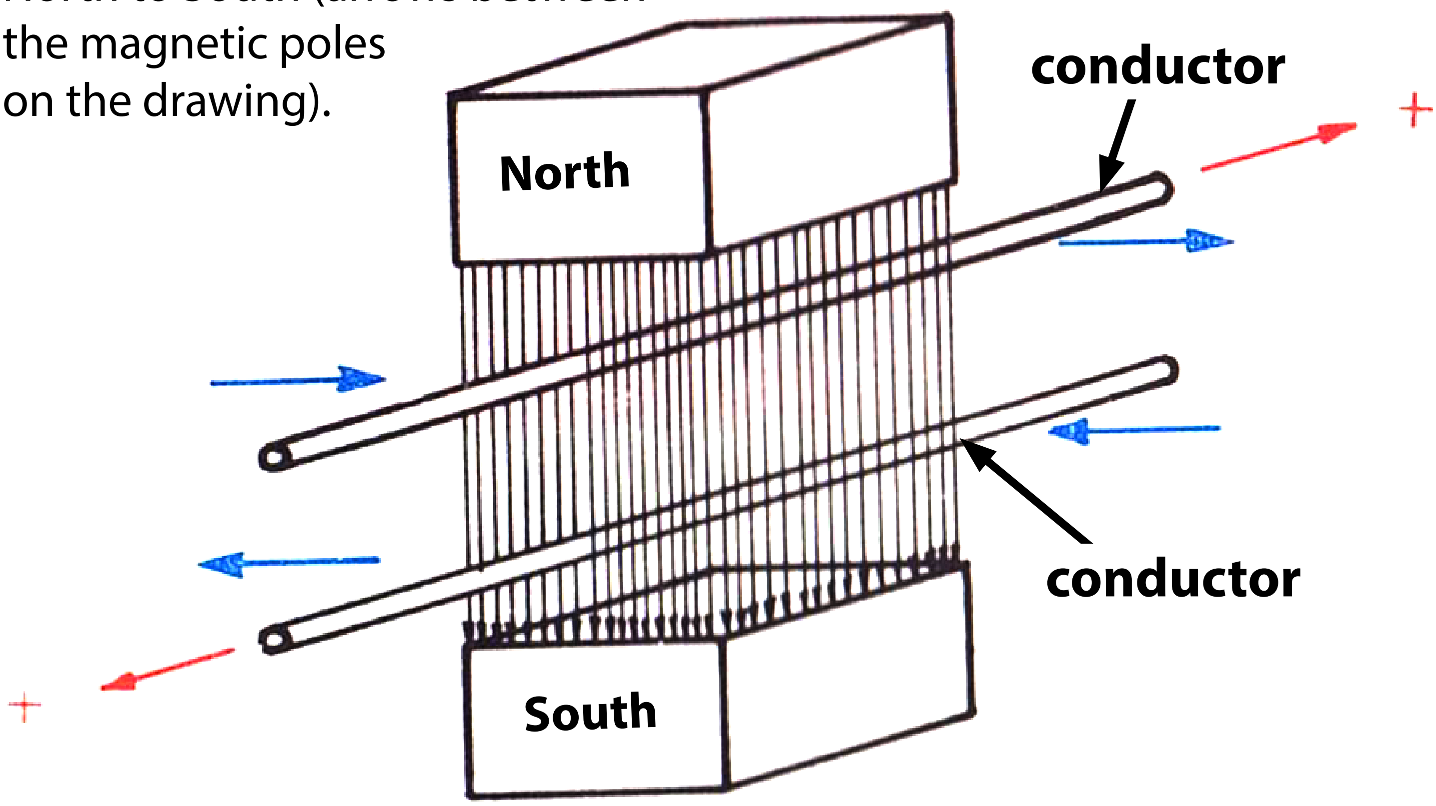
So, wouldn't it be nice to know what DF stands for, for example? And what D+ stands for? If you know what's behind those letters, codes and numbers, then connecting the dynamo or alternator will go like clockwork.
In this article, we will explain the principle operation of the dynamo, also called a direct current generator. But, we start first with the beginning, the origin of electric current.

Generate electrical current

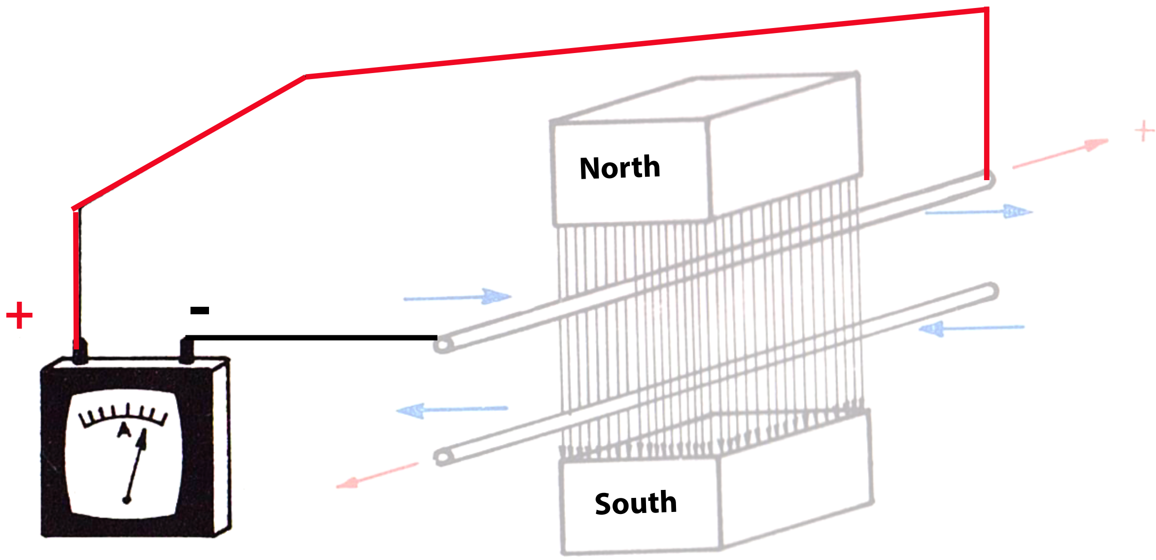
Now, if we go back to basics, and try to understand how a generator can produce electric current, we need to see what happens when an electric conductor (electric cable) moves in a magnetic field.
For this we dive into old textbooks and find beautiful drawings that we will share with you.
We take a permanent magnet, such a permanent magnet has a North Pole and a South Pole. The magnetic field lines run from North to South (arrows between the magnetic poles on the drawing).

Now what happens when we move an electrical conductor between the poles of this permanent magnet?





dynamo operating principle



What interests us in explaining the operation of an electric generator (or motor) are the magnetic field lines present on the inside of the magnet. Indeed, we will use these to produce an electric current.

The experiment goes like this. You take an electrical conductor (cable) and let it cross the lines of force of the magnet, the blue arrows on the drawing illustrate this. If you connect an ammeter to the moving cable, you will observe an electric current as the cable traverses the lines of force.

The voltage associated with this is called **Electromotive Force** or short **EMF**.

Now if you move the cable in the other direction, **EMF** is created again but with reverse polarity.

If you repeatedly move the cable from left to right and right to left, the current (or voltage) fluctuates from positive, to zero, to negative, to zero, to positive ...

Eureka, you've discovered alternating current (or alternating voltage).

#78 Electrical

Eureka! *You have discovered the generator! Unfortunately (or fortunately) Alessandro Volta had already done so over 200 years ago. To make a usable generator for our car, we need some further development.*

When the electrical conductor moves perpendicular to the lines of force of the magnet, the developed EMF is maximum. The factors below determine how large the developed EMF will be:

1. **the greater the force of the magnetic field, the greater the voltage developed**
2. **the faster the conductor moves between the magnetic field lines, the greater the voltage developed**
3. **the longer the electrical conductor is that moves between the magnetic field lines, the greater the voltage developed**
4. **the direction of movement determines the polarity of the developed voltage**

We can represent these factors in a simple formula (derived from Faraday's law), as follows: the EMFF developed is greater the stronger the magnet, the greater the length of the electrical conductor and the greater the speed at which the conductor moves. Summarized in a mathematical formula:

$$EMF = B \times l \times v$$

B = the field strength of the permanent magnet, this is expressed in tesla

l = the length of the electrical conductor, expressed in meters

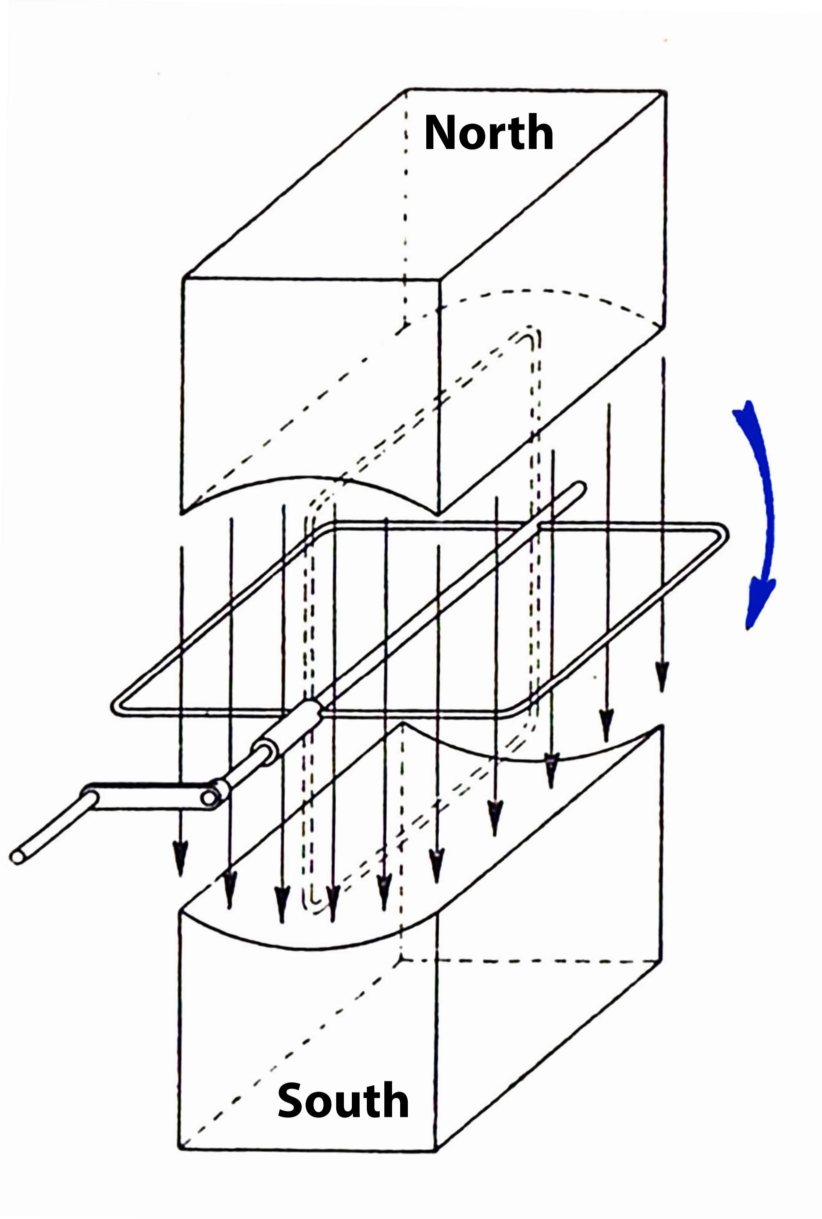
v = the speed at which the conductor moves in the magnetic force field, expressed in meter per second

Taking a medium-sized permanent magnet of 0.1 tesla, a conductor of 0.1 meter and moving it at a speed of 4 km/h (= 1,11 meter per second) perpendicular to the magnetic lines of force, we obtain a voltage of:

EMF = 0.1 x 0.1 x 1.11 = 0,01 volt

This is not enough to recharge our battery. This arrangement is also not practical in practice. It is much more practical to rotate the conductor on a shaft driven by the engine (crankshaft) of our car.

Such an arrangement in which the conductor rotates between the magnetic poles is shown in the drawing below.



You replace the crank with a crankshaft and you have the basis for an automobile generator.

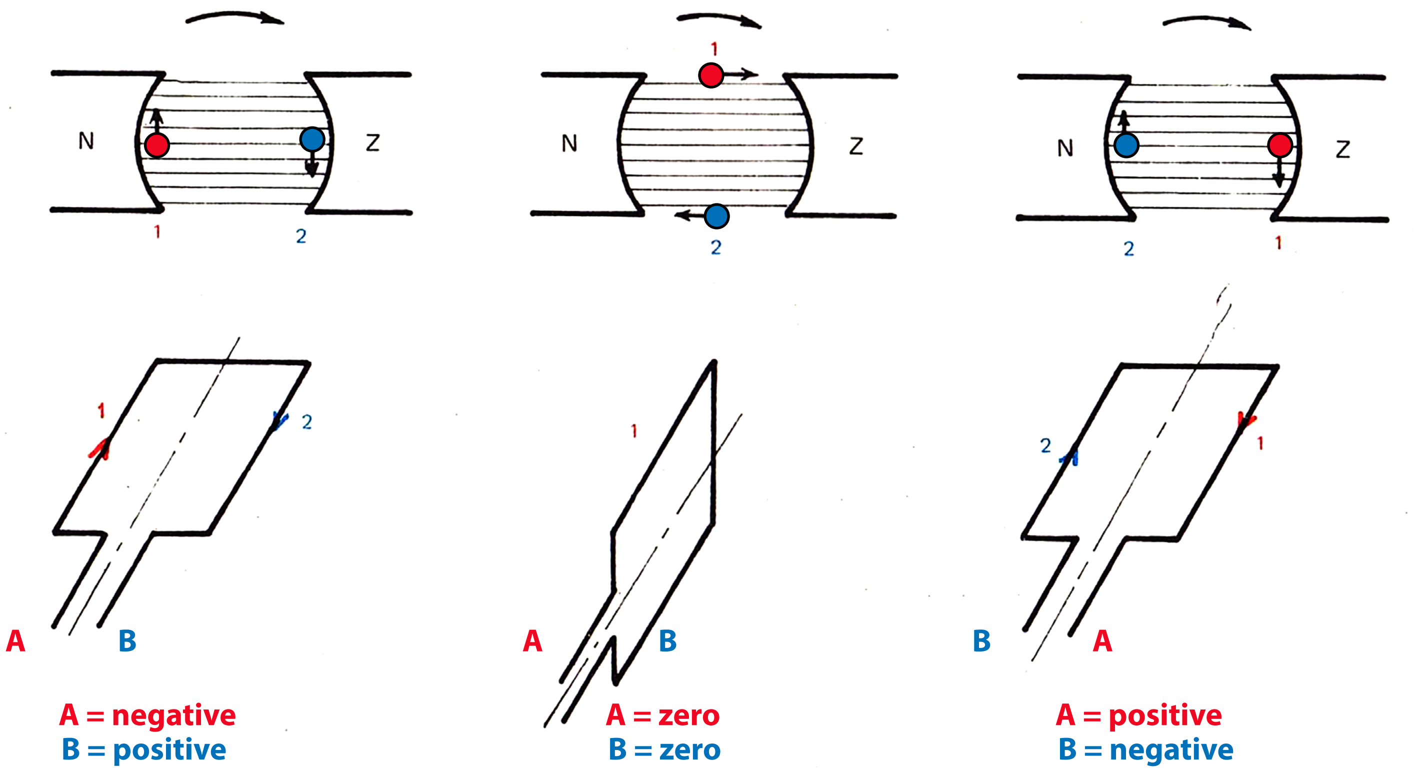
#78 Electrical

If we rotate the conductor as shown in the drawing on the previous page and below, it will not always move perpendicularly through the magnetic lines, and thus the EMF will not always be maximum. The generated current will be strongest when the conductor traverses the magnetic lines perpendicularly (drawing on the far left and far right below), and the generated current will be zero when the conductor is moving parallel to the magnetic lines of force (middle drawing below).

Therefore, we need to modify the formula from page 36 as follows (if only we had paid attention in Math class I now hear many thinking):

EMK = B x l x v x sin(angle)

On the next page, we show values for the sine for an angle from zero to 360°. Calculation of the sine of an angle can be done with a scientific calculator.



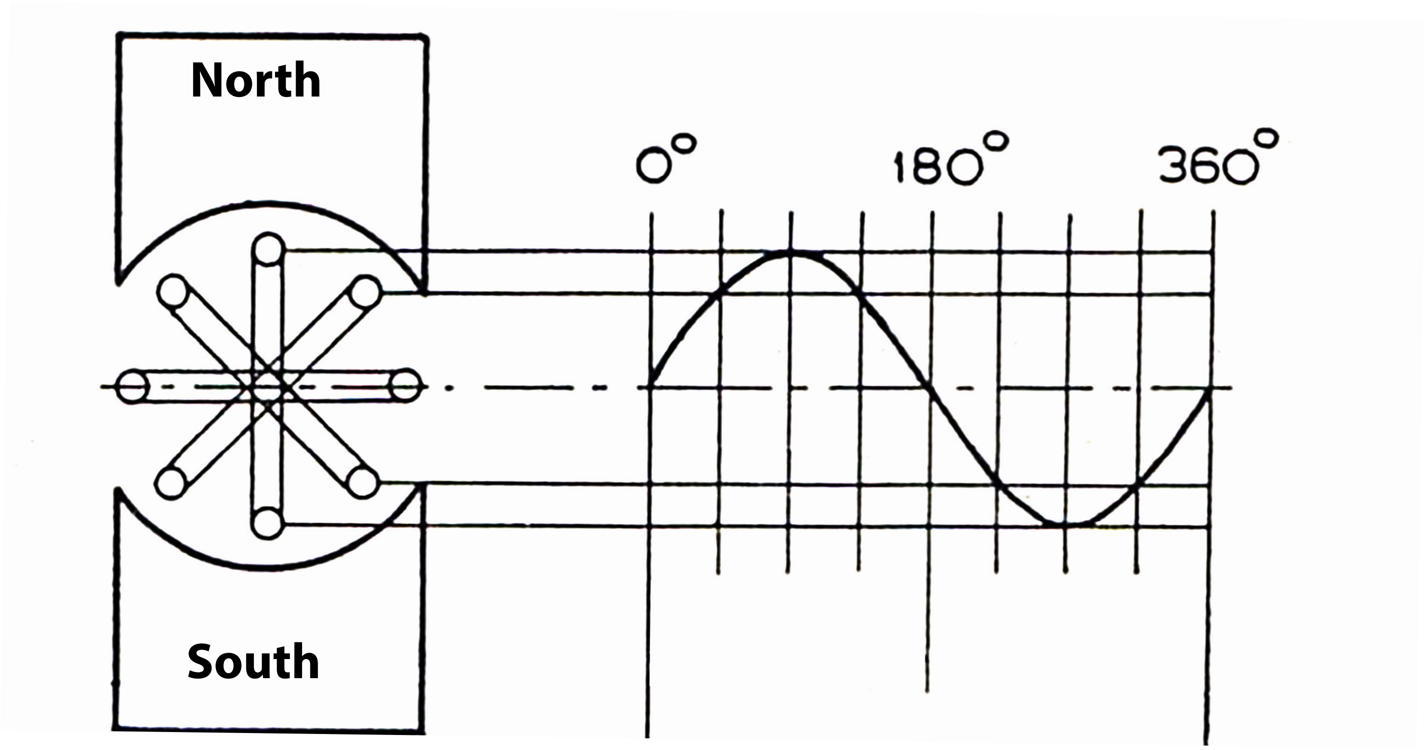
So the EMF generated will be maximally positive when the electric conductor crosses the magnetic force lines at 90° angle, and maximally negative at 270° angle, and zero at 0° and 180° angle.

angle	sin(angle)
0°	0
45°	0,71
90°	1
135°	0,71
180°	0
225°	-0,71
270°	-1
315°	- 0,71
360°	0

And there we have the alternating voltage (or alternating current) we discussed in edition 17.

Below we show the permanent magnet with an electric conductor rotating between the magnetic poles and crossing the lines of force. To its right, we have drawn the voltage level at each angle.

If you calculate the formula for each angle, and replace the sine of the angle with the values from the table, you obtain a sinusoidal voltage curve as shown below.



When the conductor crosses the magnetic lines of force perpendicularly (90°), then the EMF developed is maximum. If it crosses the lines of force at a different angle, then the EMF will become smaller, it will be multiplied with the sine of the angle. The polarity will reverse when the conductor changes direction.

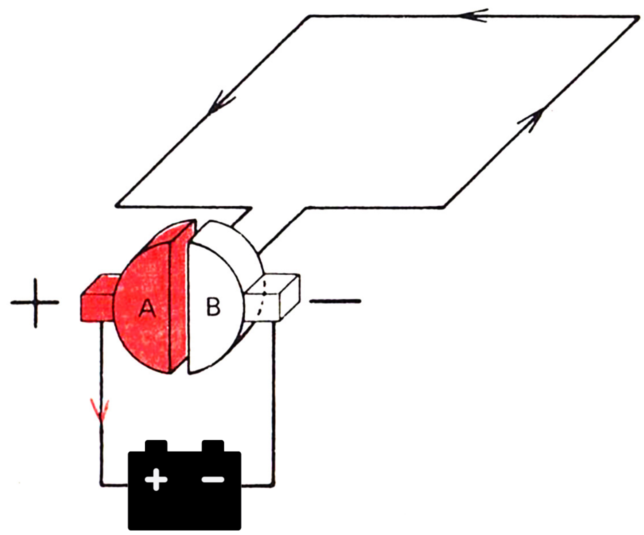
#78 Electrical

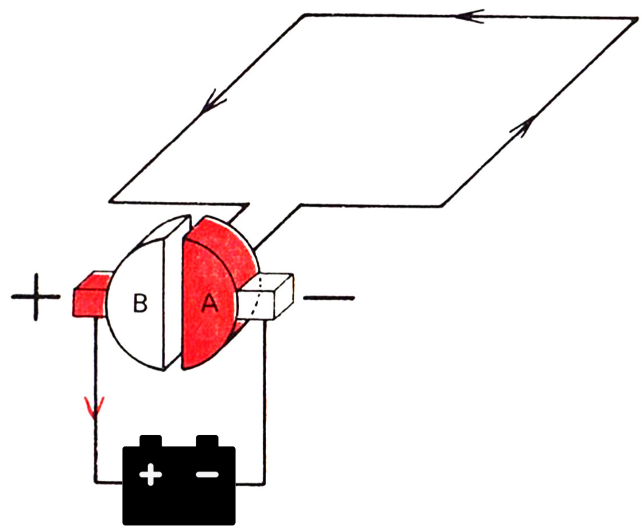
The voltage developed by any type of generator is an alternating voltage. As mentioned earlier, the battery of our car can only be recharged with a direct voltage. To convert the alternating voltage into a direct voltage, we connected the conductor to the electrical consumer by means of a commutator.

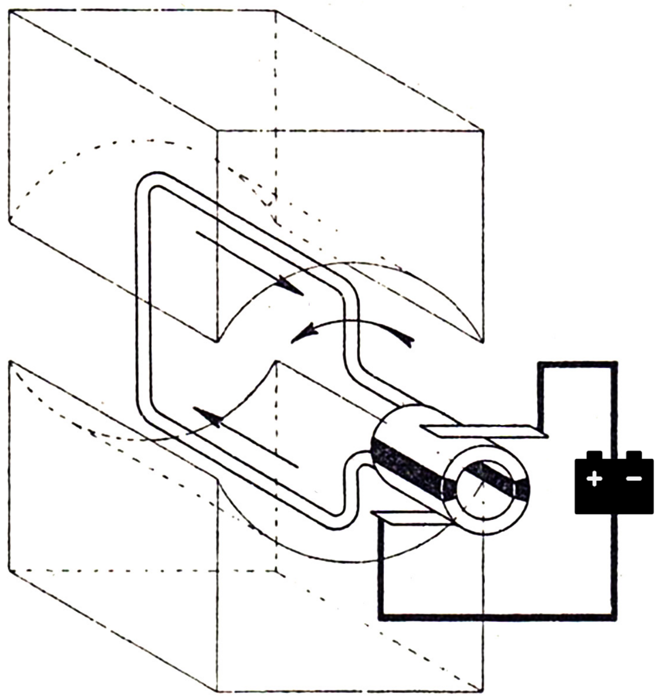
We show the principle of the commutator in the drawings below. The conductor, which rotates between the magnetic poles, is connected to the commutator. The commutator makes contact with the consumer (in this case, a battery) through a carbon brush.

Each time the voltage passes through zero volts, the direction of the current through the electrical consumer is reversed. The negative portion of the sine wave now becomes positive. This is called **rectifying** an alternating voltage.

In the drawings below, imagine the commutator spinning, with the conductor attached. The carbon brushes slide over the smooth copper surface of the commutator and conduct the electric current to the consumer.

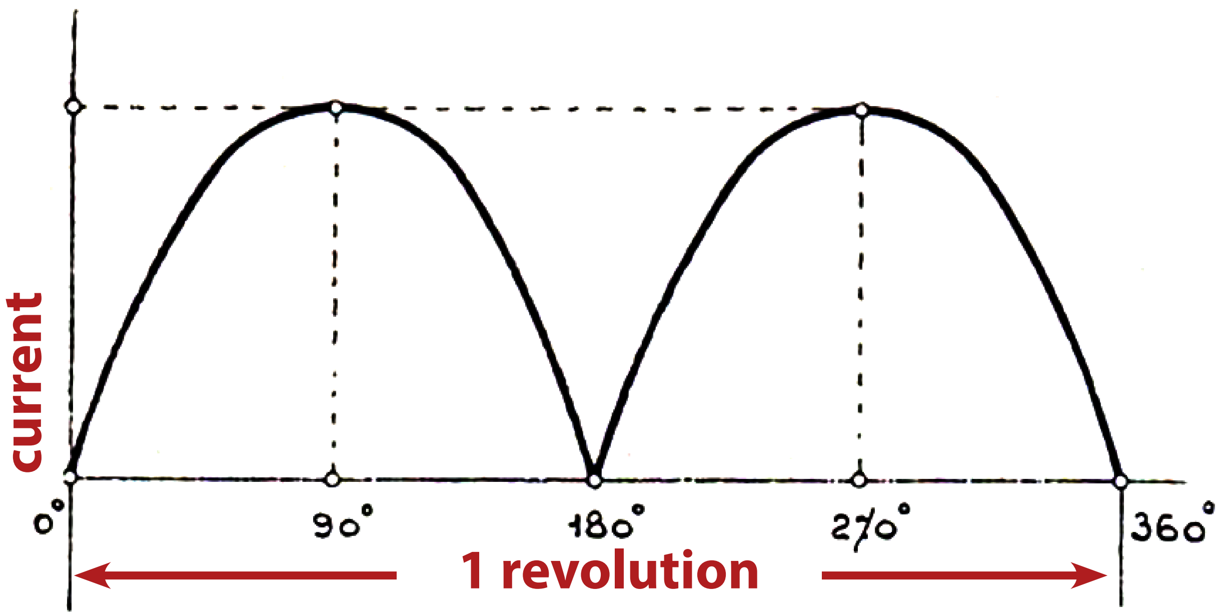






In practice, the commutator is a copper slip ring (drawing on the right), divided into equal parts by insulation materials. The result is that the voltage at the output of the generator is now no longer of the alternating voltage type, but a direct voltage.

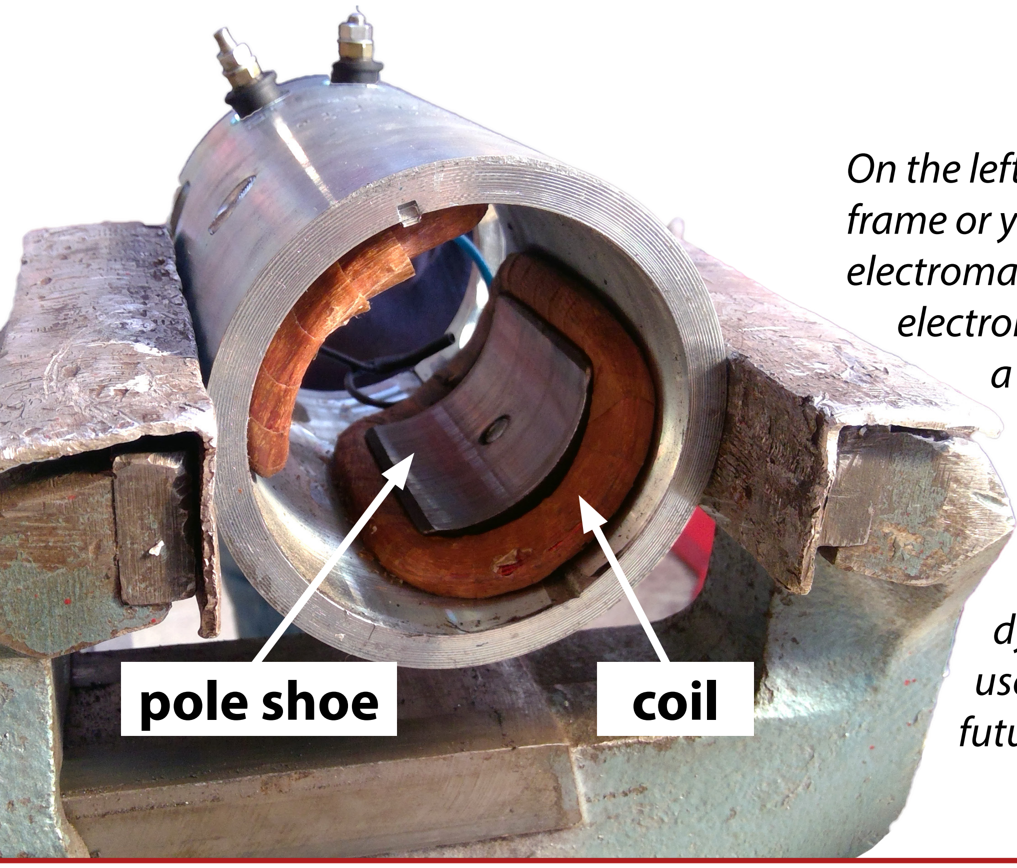
So the result after introducing a commutator is a DC voltage. But this DC voltage is still very irregular, and too weak. To obtain a stronger and flatter voltage, several copper conductors (windings) are placed in series connection between the magnet. By connecting them one after the other, the currents generated add up and the voltage generated becomes flatter. All those windings are wound onto a soft iron core, with the ends connected to the commutator. The whole then forms the armature of the dynamo.



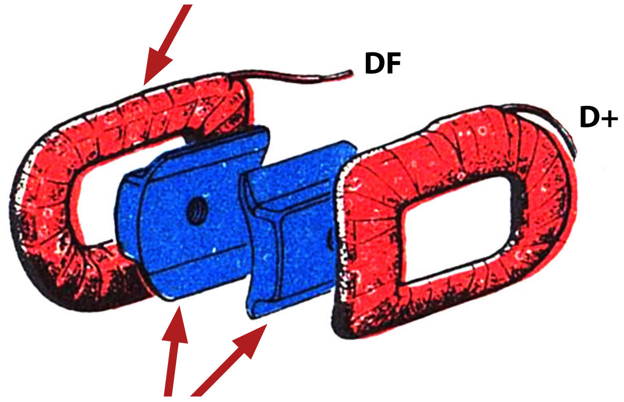
Permanent magnet replaced with an electromagnet

The theory of the previous pages is promising, but **a voltage of 0.01 volts is not strong enough**, we need at least 6 or 12 volts. The engine of our classic Volkswagen does not always run at the same speed. Therefore, the voltage developed will also not be constant, but will vary with the speed of the engine. Solutions had to be found for all these limitations.

To develop the necessary 6 or 12 volt voltage we would have to use a giant permanent magnet. This is not feasible to build that into our car. It would increase the cost, the available space, as well as the weight. A permanent magnet would also not allow to regulate the generated voltage with increasing engine speed. We know this from our bicycle in the past, the dynamo was equipped with a permanent magnet, and the lights shone harder the harder you pedaled. Therefore, the permanent magnet is replaced by an electromagnet (field winding).



On the left we show the dynamo frame or yoke containing the electromagnet (field winding). The electromagnet of a dynamo has a weak magnetic field after turning off the voltage at the DF terminal, this is remanent magnetism. It is therefore important that a dynamo be polarized before use. We will explain this in a future issue.

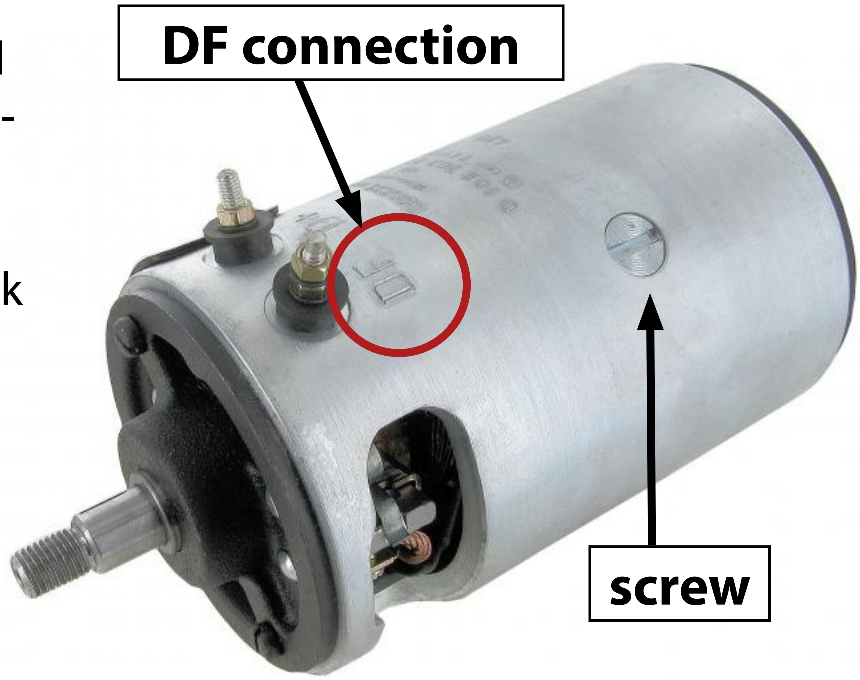


An electromagnet consists of a ferromagnetic core, for example soft iron, around which a coil is wound (drawing on the right). On the previous page we show such an electromagnet in a Bosch dynamo. This electromagnet is many times more powerful than a permanent magnet and will boost the **B** in the EMF formula of page 38.

EMF = B x l x v x sin(angle)

On the previous page you see the frame of a Bosch dynamo in the vise. The rotating part (the armature) is disassembled and you can see the field windings with their pole shoes inside the frame. The pole shoes are securely fastened with thick screws (photo at right). The strength of the electromagnet depends on the voltage connected to the field winding (DF, F stands for FIELD).

And that's going to be interesting! You can use this setup to control the developed voltage (EMF) by controlling the voltage on the field winding (DF). Thus, depending on the rotational speed of the engine, you can adjust the output of the dynamo.



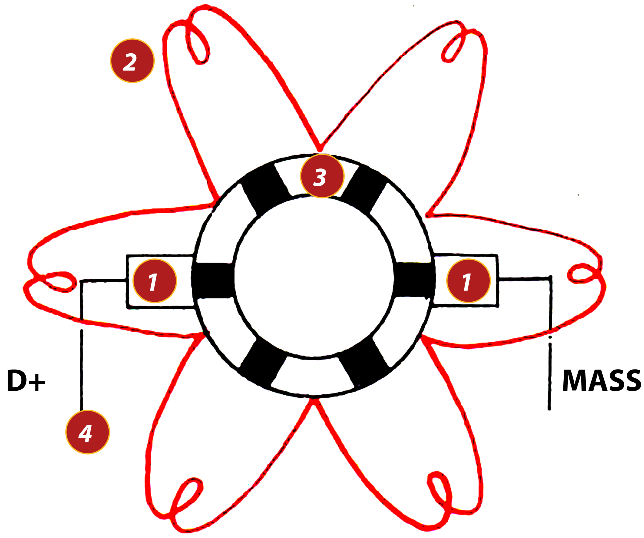
The field windings (coil) we already showed on page 44, then still mounted in the dynamo housing, we now show below separately. On the left with paper protective tape used to protect the coil windings before securing them in the dynamo frame, on the right with the tape removed. The field windings are made with thin copper conductors. The current the field windings are allowed to use must be kept to a minimum so as not to overload the battery. Each field winding will be a magnet pole, North or South pole, that will depend on the polarization voltage connected to the field windings during the configuration of the dynamo. We will come back to this when we will overhaul and polarize a dynamo in a future edition.

field windings

Longer conductor: the armature

In a dynamo, the one conductor we showed earlier is replaced by a multitude of thick copper conductors, which form the armature windings. In doing so, we increase the length of the conductor, and as you can read from the EMF formula, the longer the conductor the greater the EMF:

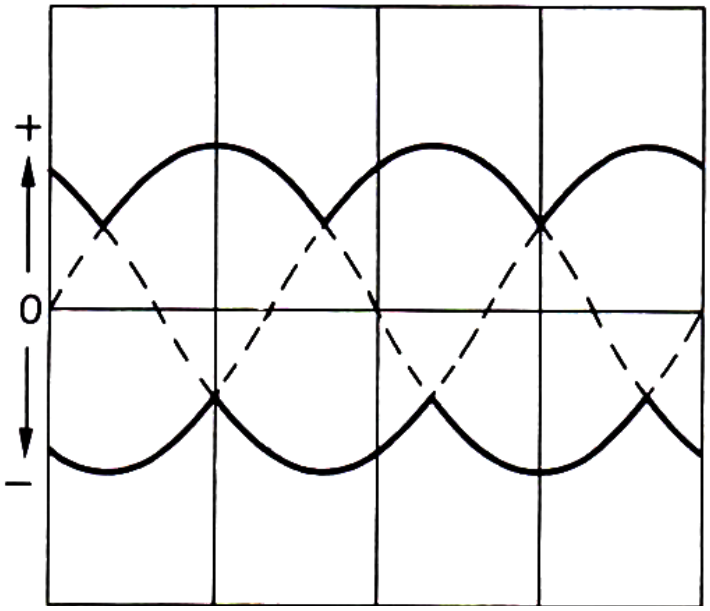
EMK = B x l x v x sin(angle)



Instead of one winding with one long conductor, several windings are applied to the armature. The reason for this is that more windings in series will generate a flatter voltage.

The drawing above shows how the different windings of the armature are coupled together in series connection on one lamella of the commutator each time.

Connecting the conductors in series will form the armature (the armature windings). The different windings will intersect the magnetic forces at different times, the result being different sinusoidal voltages that add up. On the right we show the result.



Because the armature uses thicker copper conductors, it will be able to withstand more current. Consequently, this is necessary because the armature must provide the charging current to the battery.

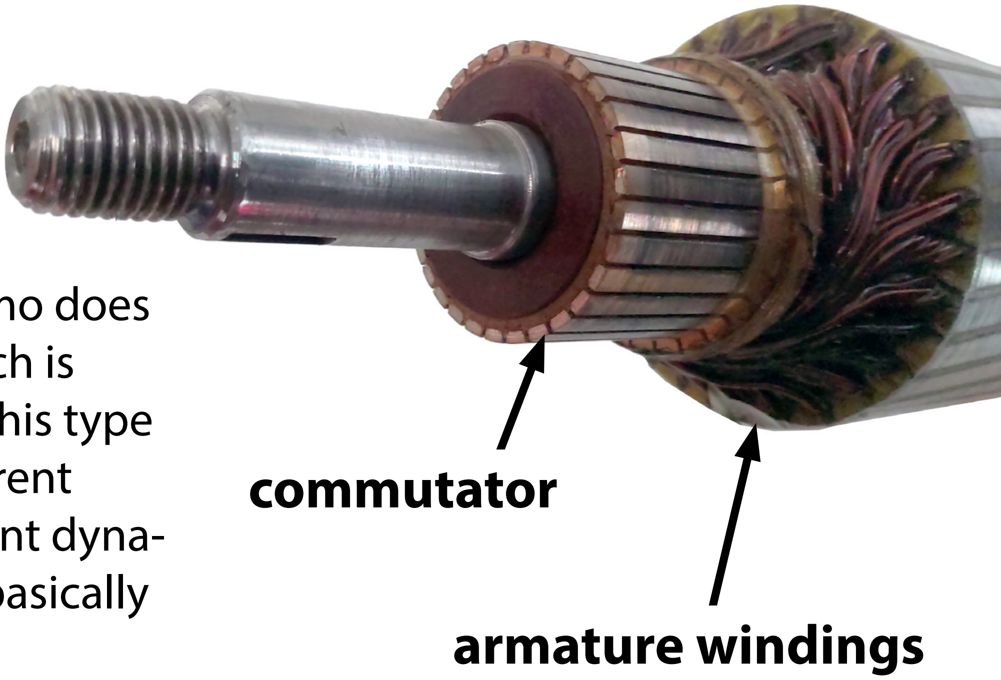
Rectifier: the commutator and carbon brushes

As mentioned earlier, the battery in our car needs a DC voltage to recharge. The voltage delivered by the armature windings is an alternating voltage (top right drawing). It is the commutator of the dynamo that causes AC voltage to be transformed into a DC voltage. Whenever an armature winding changes direction, in other words, whenever the armature winding crosses the magnetic force lines of the field winding in the opposite direction, the commutator will cause the polarity to reverse.

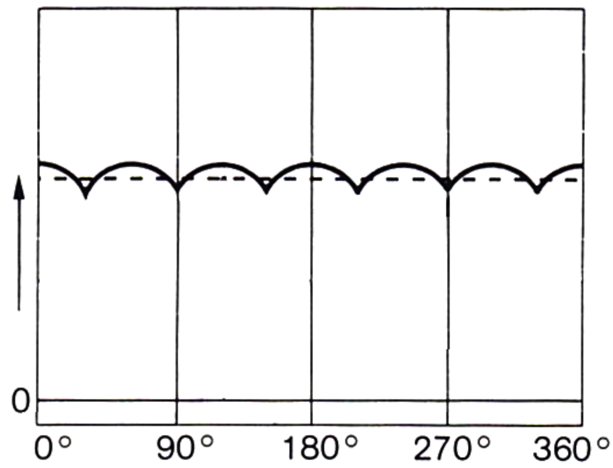
We show this in a graph on the next page. In practice, the voltage will be even flatter because there are many armature windings. The commutator is a slip ring divided into several contacts.

dynamo operating principle

The commutator of the dynamo turned the AC voltage into a DC voltage; the AC voltage was **rectified**. The dynamo does this itself, internally, which is why we sometimes call this type of generator a direct current generator or direct current dynamo. The commutator is basically a mechanical rectifier.

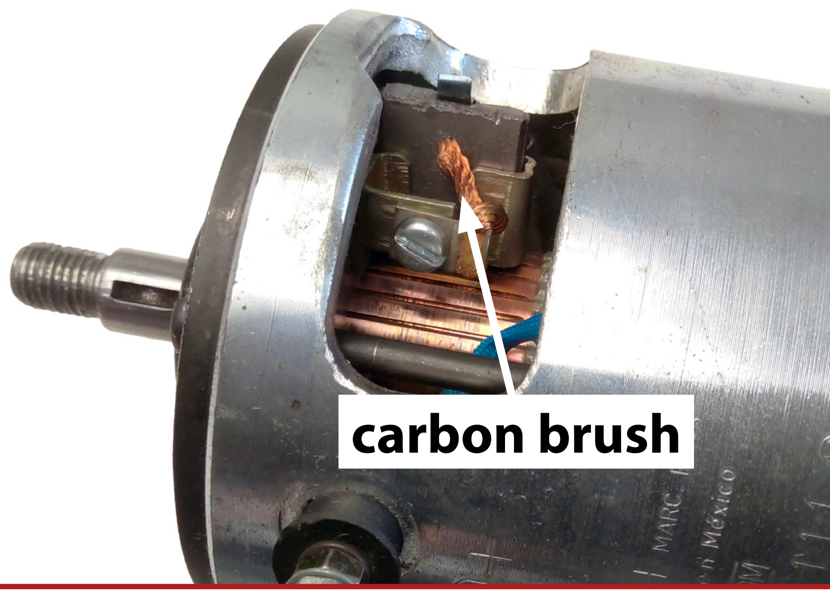


On the right we show the voltage curve at the output of the dynamo. It is not completely flat, but by adding additional armature windings, the voltage becomes virtually constant (flat). This is the voltage at the D+ terminal of the dynamo, it is connected to the D+ terminal of the voltage regulator.



Carbon brushes

The carbon brushes (photo right) slide over the slip ring of the commutator and will take turns connecting the voltage of each armature winding to the terminals on the outside of the dynamo. This connection is indicated by **D+**.



#78 Electrical

The Bosch dynamo

This summary drawing shows all the parts of a dynamo (direct current) as we will encounter on older classic Volkswagens.

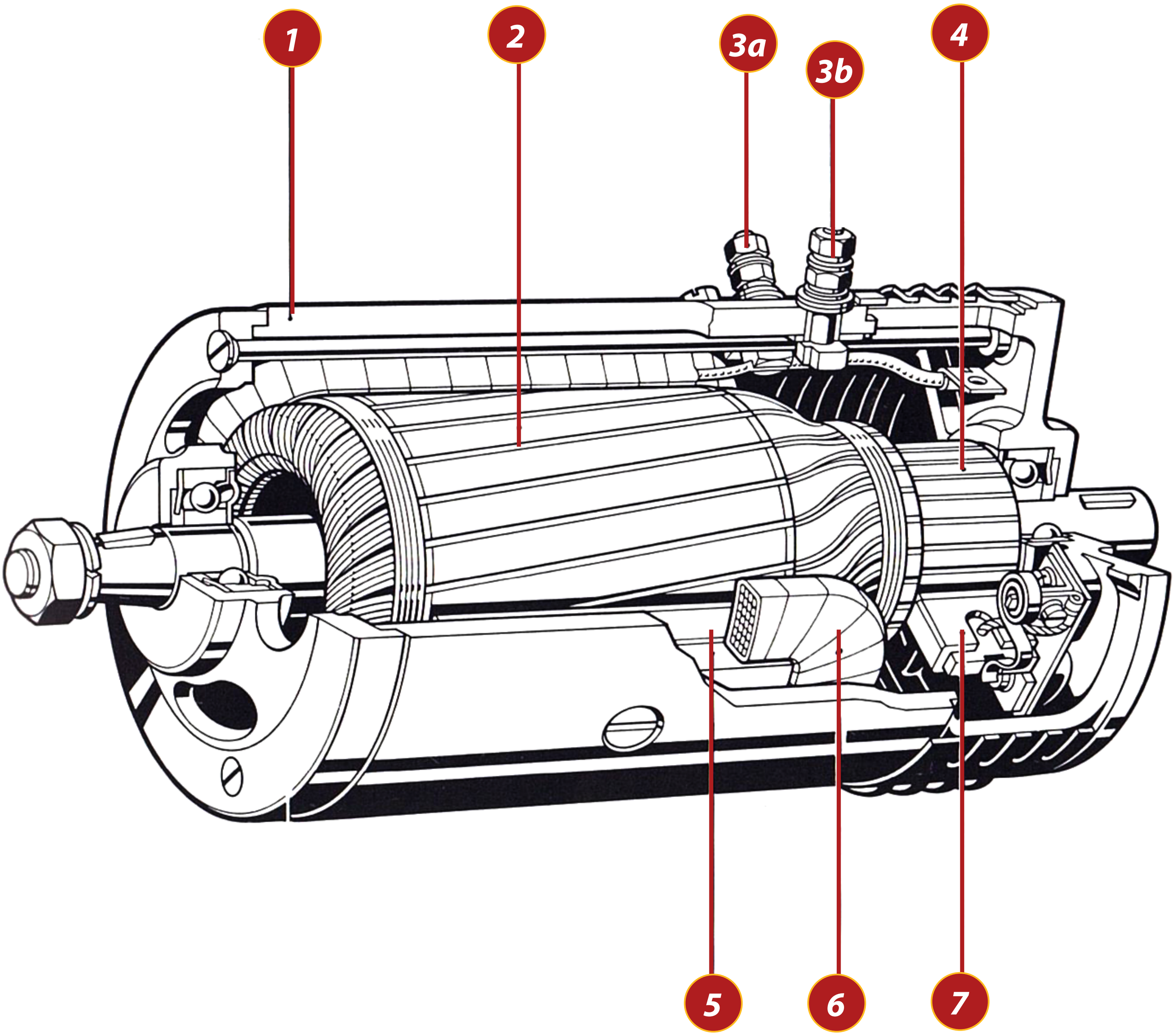
The dynamo was used in the automotive industry for a long time, until the late 1960s, early 1970s. The great advantage of the dynamo is that it takes care of rectifying the output voltage itself, and does so with mechanical parts. Namely, it is the slip ring (the commutator) that takes care of reversing the current every time the current reaches zero. No need for electronics components, which at that time were still large, expensive and consumed a lot of energy.

The big disadvantage of the dynamo became apparent when everyone started to get stuck in traffic jams on the highway, or in the city, sometime in the mid-1960s. The dynamo generates little current when the engine

- **1** **dynamo frame or yoke**
- **2** **armature with armature windings**
- **3a** **DF field windings =>**
  DF voltage regulator
- **3b** **D+ => D+ voltage regulator**
- **4** **commutator**
- **5** **pole shoe**
- **6** **field windings**
- **7** **carbon brushes**

is idling (at 800 r/min). Charging current comes only at approximately 1200 rpm. In the VW Beetle, therefore, the crankshaft pulley to dynamo pulley ratio was calculated to make the dynamo spin faster than the crankshaft. Another disadvantage of the dynamo is its maximum charging current. This is because the entire charging current flows through the armature windings via the commutator and carbon brushes. This creates sparks between carbon brushes and

dynamo operating principle



commutator, so the direct current dynamo components have a shorter lifespan than an alternator. Why is that? Well, we'll explain that in the next edition of this technical series.

Paruzzi
CLASSIC CAR PARTS

Paruzzi Magazine

591856

www.Paruzzi.com/magazine