Paruzzi Magazine

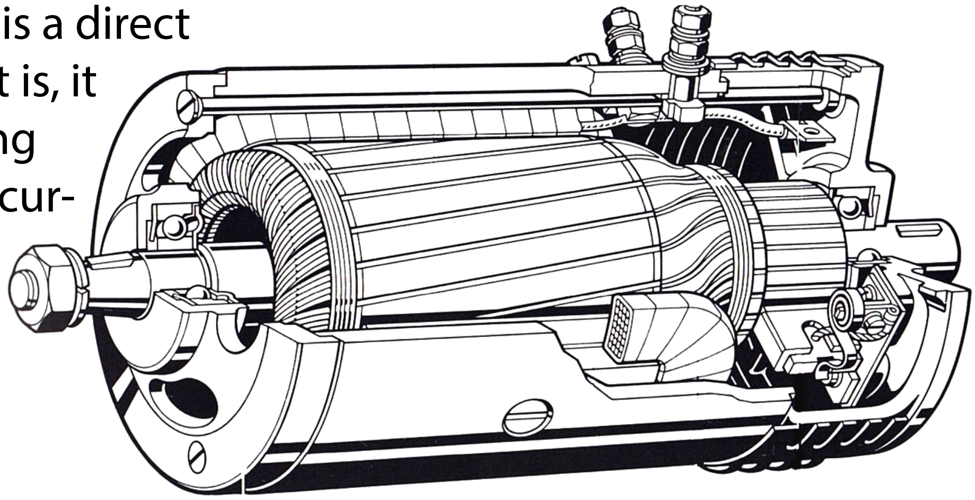
Digital Publication for the classic Volkswagen

27

Introduction

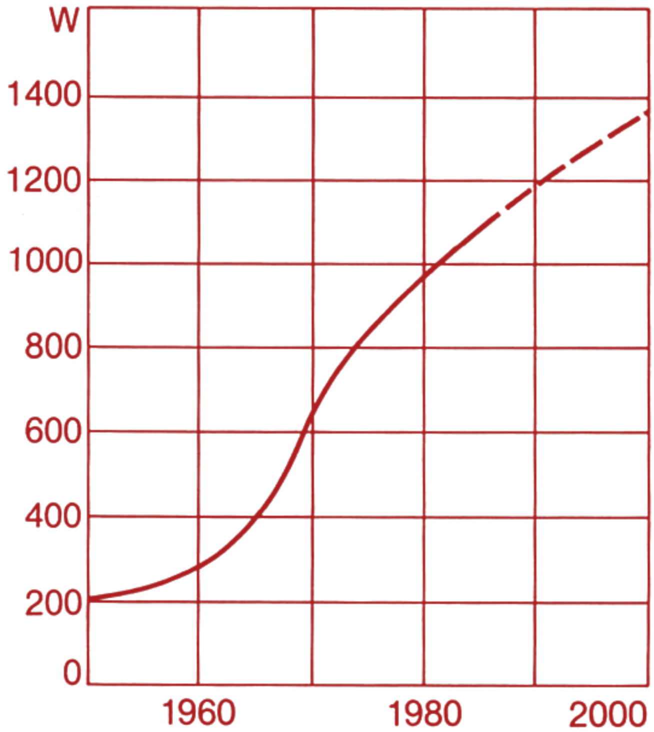
In edition 26, we explained how electric current is generated. Moving an electrical conductor back and forth between the field lines of a magnet is sufficient to generate an alternating current. The electric generator in our VW works with this principle.
In the oldest Volkswagens, the electric current is supplied by a dynamo. The dynamo is a direct current generator, that is, it converts the alternating current itself to direct current, this is done by means of a collector built into the dynamo.

Below we show a drawing of a dynamo. The dynamo proved unsuitable for the modern car of the time in the late 1960s. We have already discussed the disadvantages of the dynamo in detail in edition 26, at the bottom of this page the disadvantages are summarized again:



- **maximum current in armature is limited**
- **limited charging current at low speed**
- **less cooling of rotating armature**
- **full charging current flows between collector and carbon brushes**
- **burn-in carbon brushes and collector**
- **complex construction of the armature**
- **the weight of the dynamo increases sharply with its power**

You have to put this in the time context, in the 1950s and 1960s. Cars had few accessories, few electrical consumers. The modern electric wiper motor was one of the major consumers, along with the headlights, semaphores and starter motor. A radio was a rare option, and that was without an additional amplifier, and with one 4-watt speaker. Not much power was needed, so the dynamo was the appropriate generator. But everything changed in the late 1960s.
On the right we show a graph from an old Bosch manual. In it they predict the evolution of the consumption of the electric circuit of the automobile until the year 2000. Like any prediction, it does not turn out to be exact, but the trend is correct. The need for a generator with more power starts somewhere in the mid-1960s and continues on an upward trend.



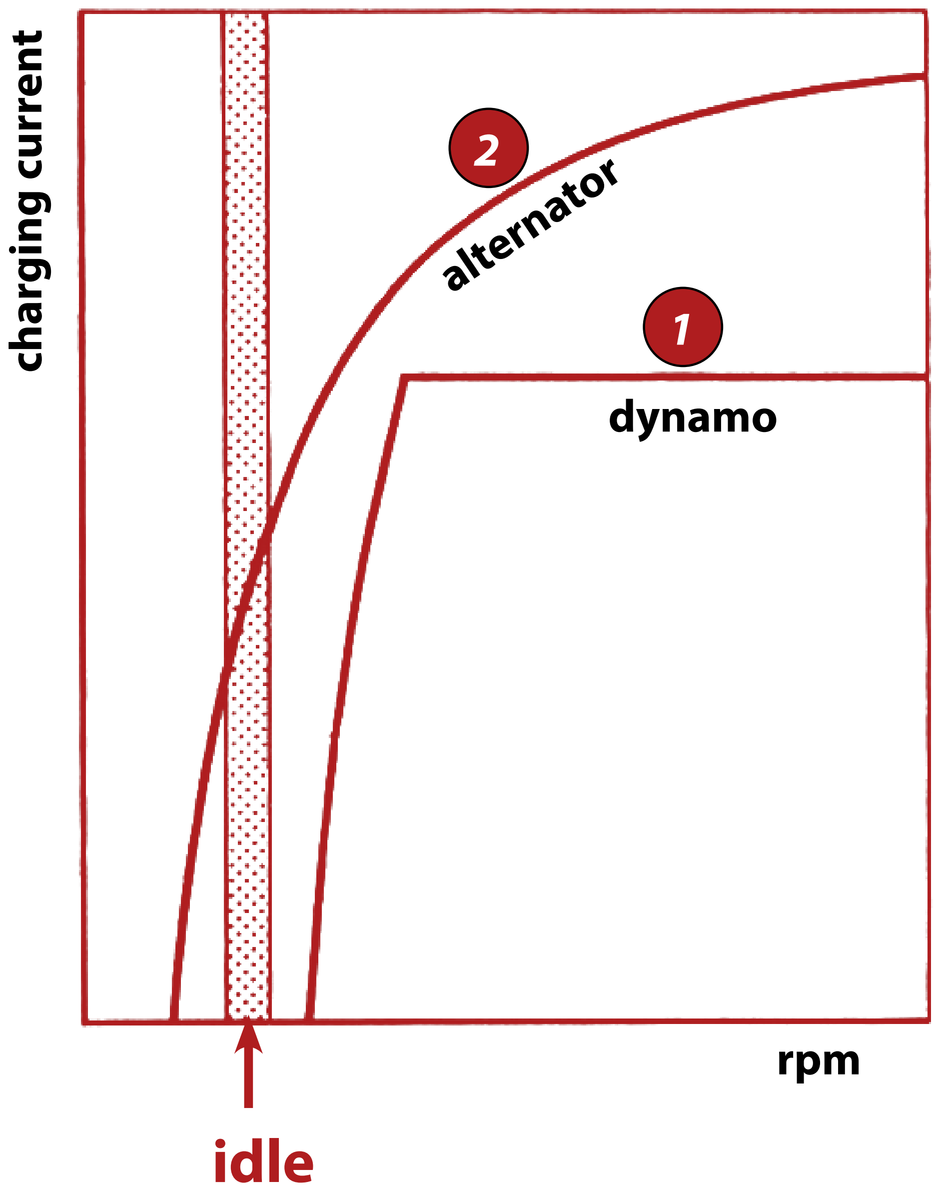
In a more recent edition of this book, they differentiate between luxury class and middle class and the predicted needed power becomes even greater.

The direct current dynamo has the limitation of maximum current (about 30 A) and a maximum rotational speed of 6000 rpm because the collector must let the full current through and the carbon brush would get too hot due to friction with the collector. More power would also make the DC dynamo too heavy and unusable in a modern automobile. There was a need for another type of generator.

Traffic also became busier in the mid-sixties, more queuing, more idling. Bosch also made predictions about this. The main disadvantage of the (direct current) dynamo is that it produces little current at low rpm. This is illustrated in the graph below.

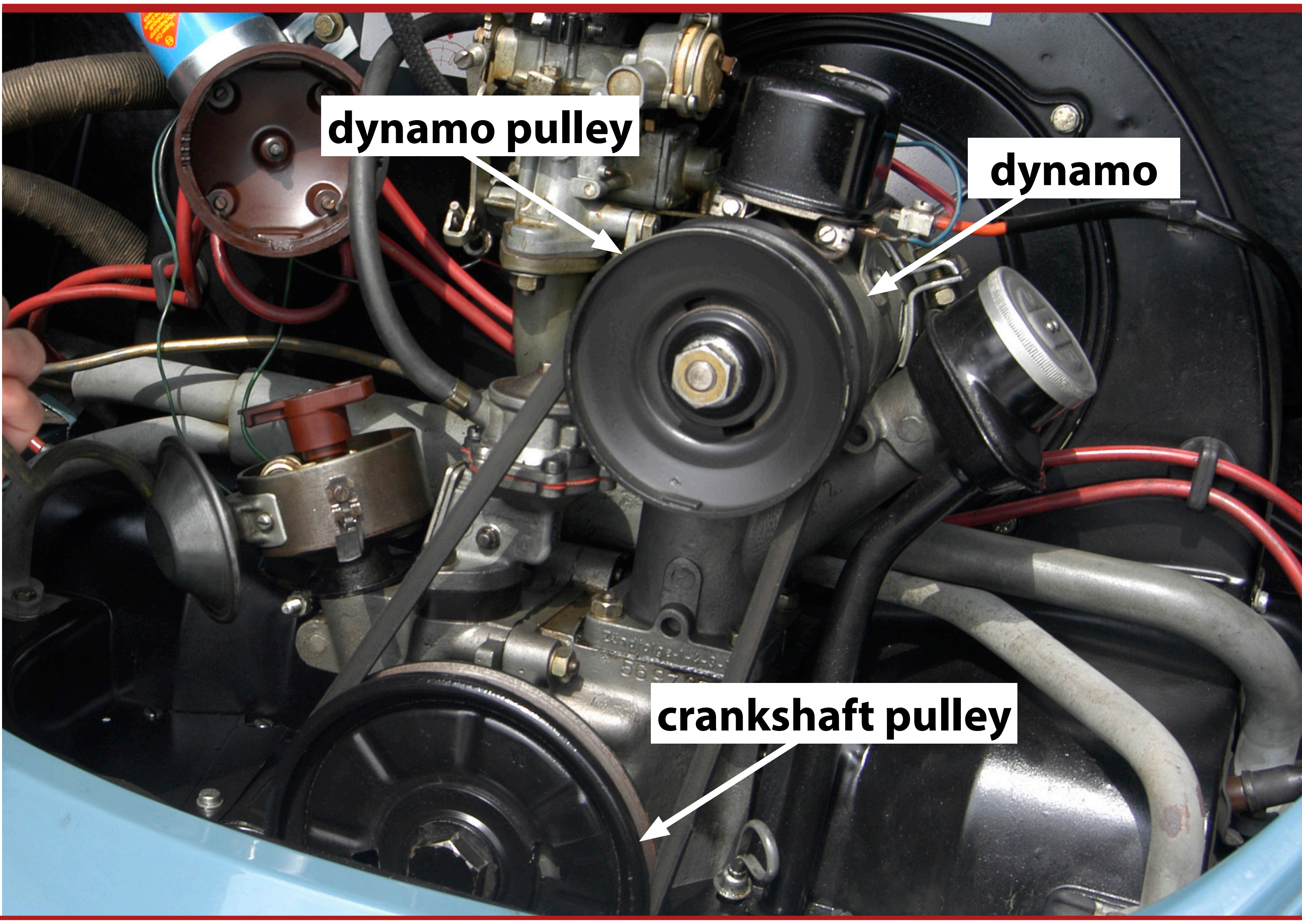
The vertical bar with dots indicates the idle speed.

Curve number 1 is this of the dynamo. At idle speed the dynamo produces no current; it is only at higher speed that the dynamo becomes productive.



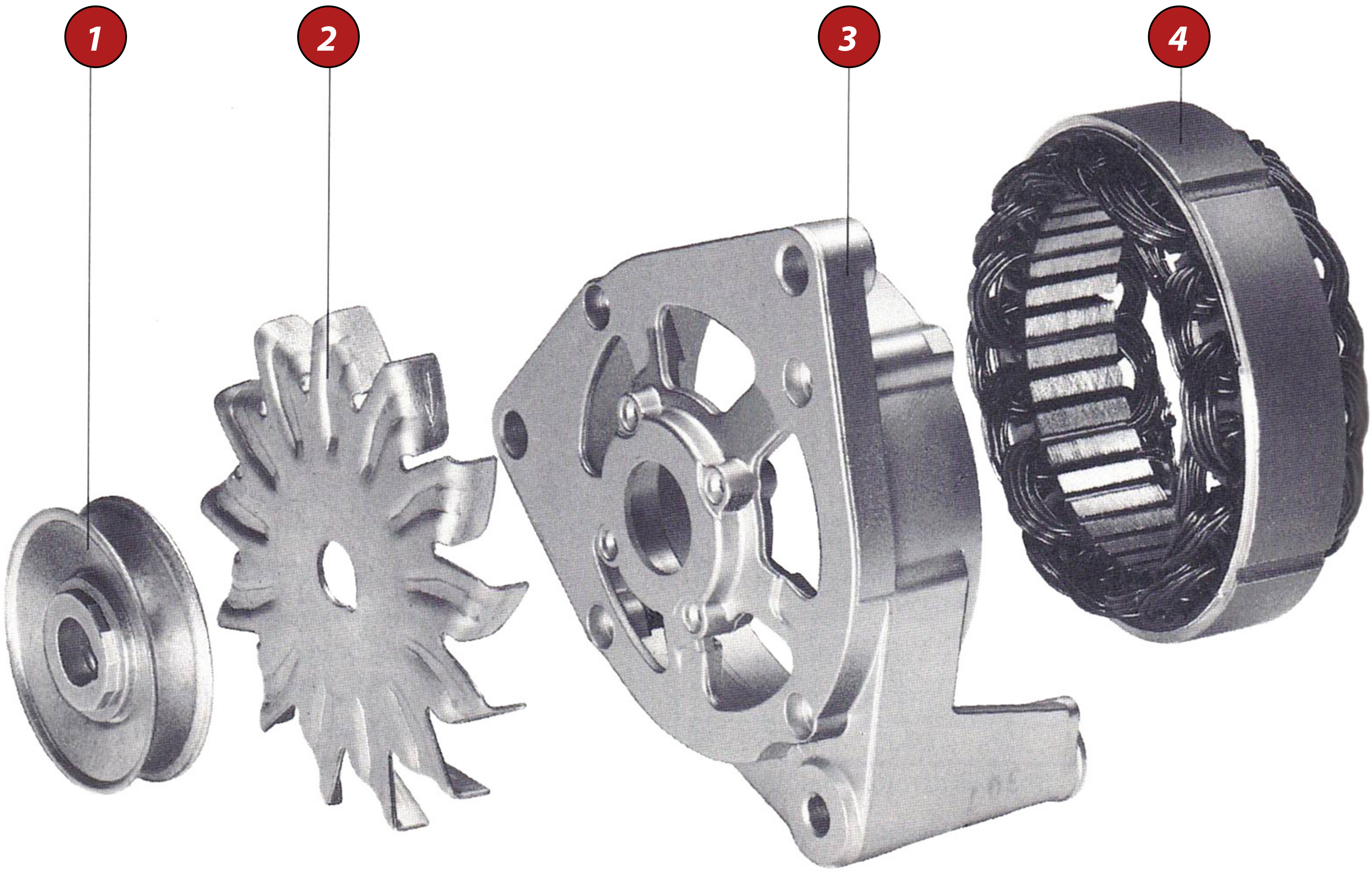
Curve number 2 is this of the alternator. The alternator begins to produce power even at very low rpm, which is a great advantage over the dynamo. The curve builds up gradually, and has usable current production between idle speed and maximum speed.

To make the dynamo work even at idle speed, the ratio of the diameter of the crankshaft pulley to the dynamo pulley was optimally calculated to make the dynamo spin faster than the crankshaft of the engine. This caused the dynamo to produce power at a lower speed. Below we show the crankshaft pulley and dynamo pulley of a 1960 34 hp engine.



The alternator

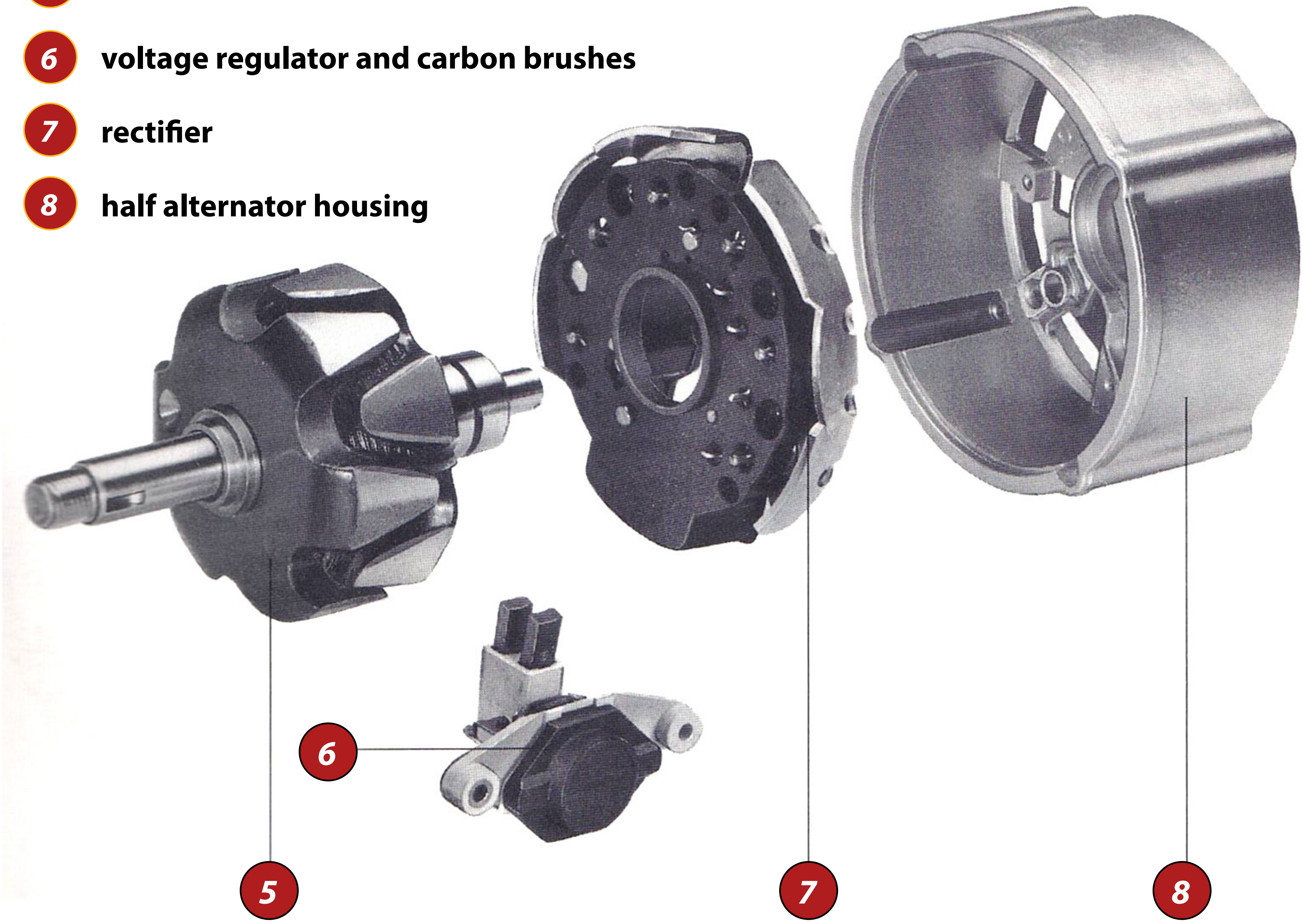
The dynamo's greatest asset turned out to be its greatest limitation, the collector. Supplying more current would shorten the life of the carbon brushes; something had to be found for that. So the dynamo was no longer adequate for the new situation of the mid-sixties. The service interval had to be increased, as owners of modern cars now drove more miles. There had to be a successor to our old dynamo; it became the alternator. We will first show an overview of the construction of the alternator and then compare with the good old dynamo, then we will discuss



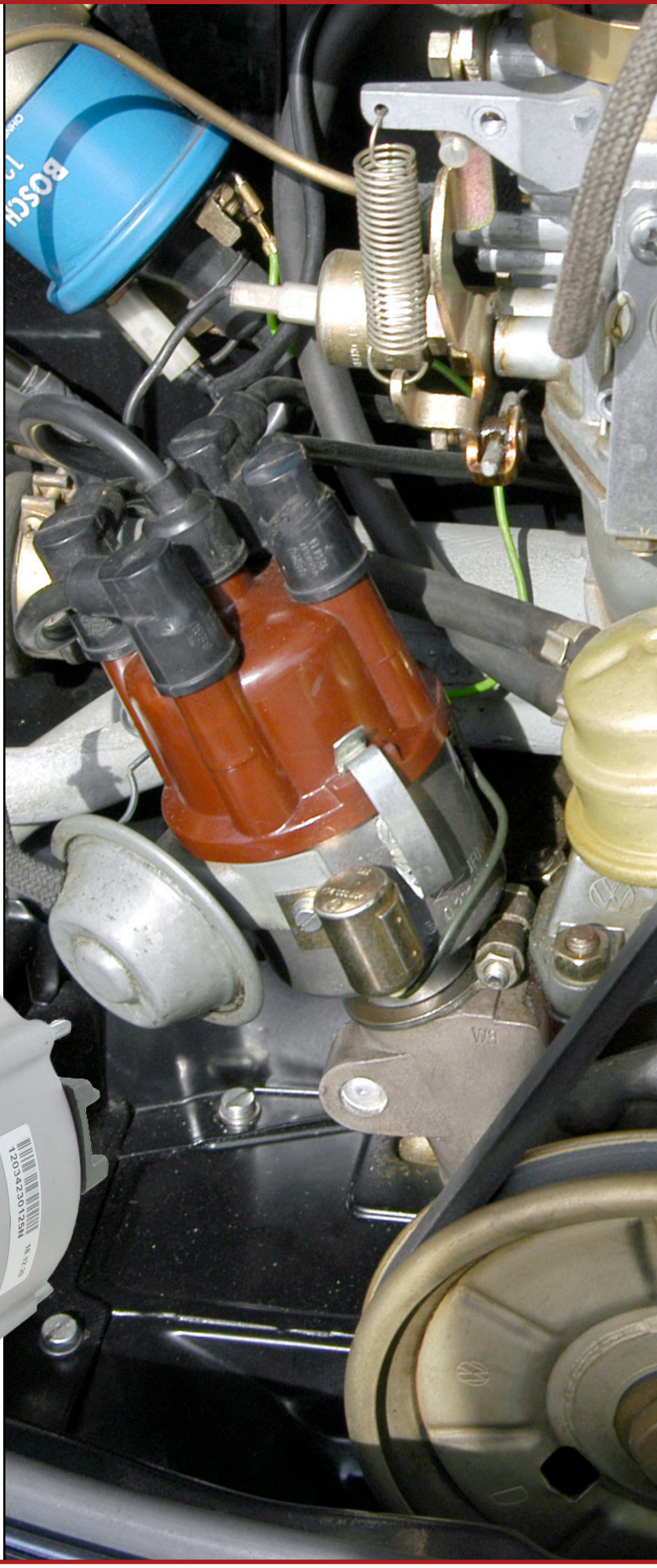
alternator operating principle

1. **alternator pulley**
2. **cooling fan**
3. **half alternator housing**
4. **stator**
5. **rotor**
6. **voltage regulator and carbon brushes**
7. **rectifier**
8. **half alternator housing**

each part of the alternator. In a future edition we will get more practical, overhauling and testing an alternator.

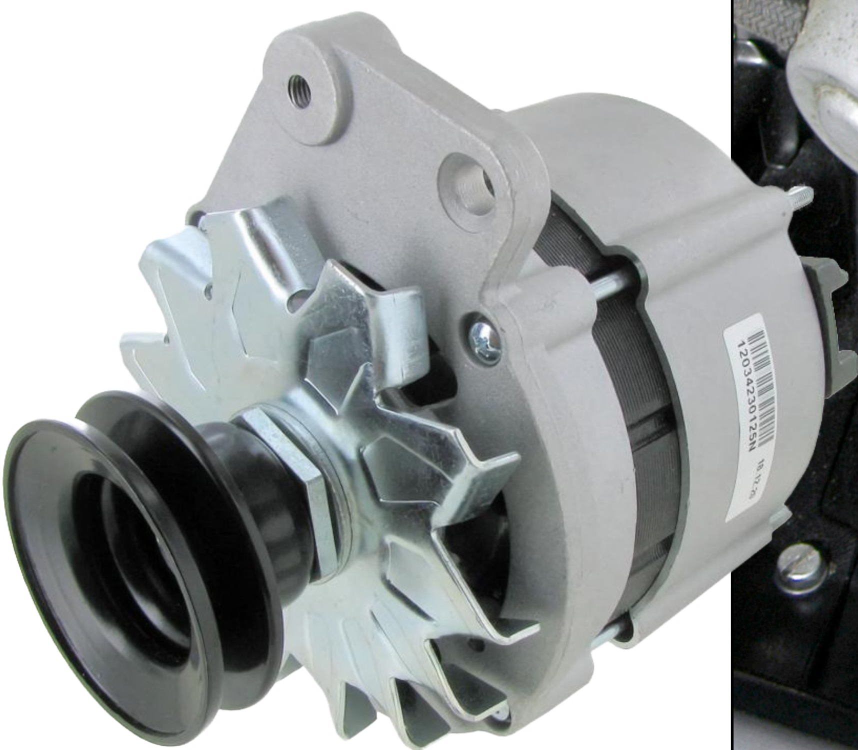


The alternator and dynamo are also called generator in the Bosch manuals; the dynamo we discussed in the previous edition is sometimes called a DC generator, the alternator an AC generator. For simplicity, we will use the terms dynamo and alternator.

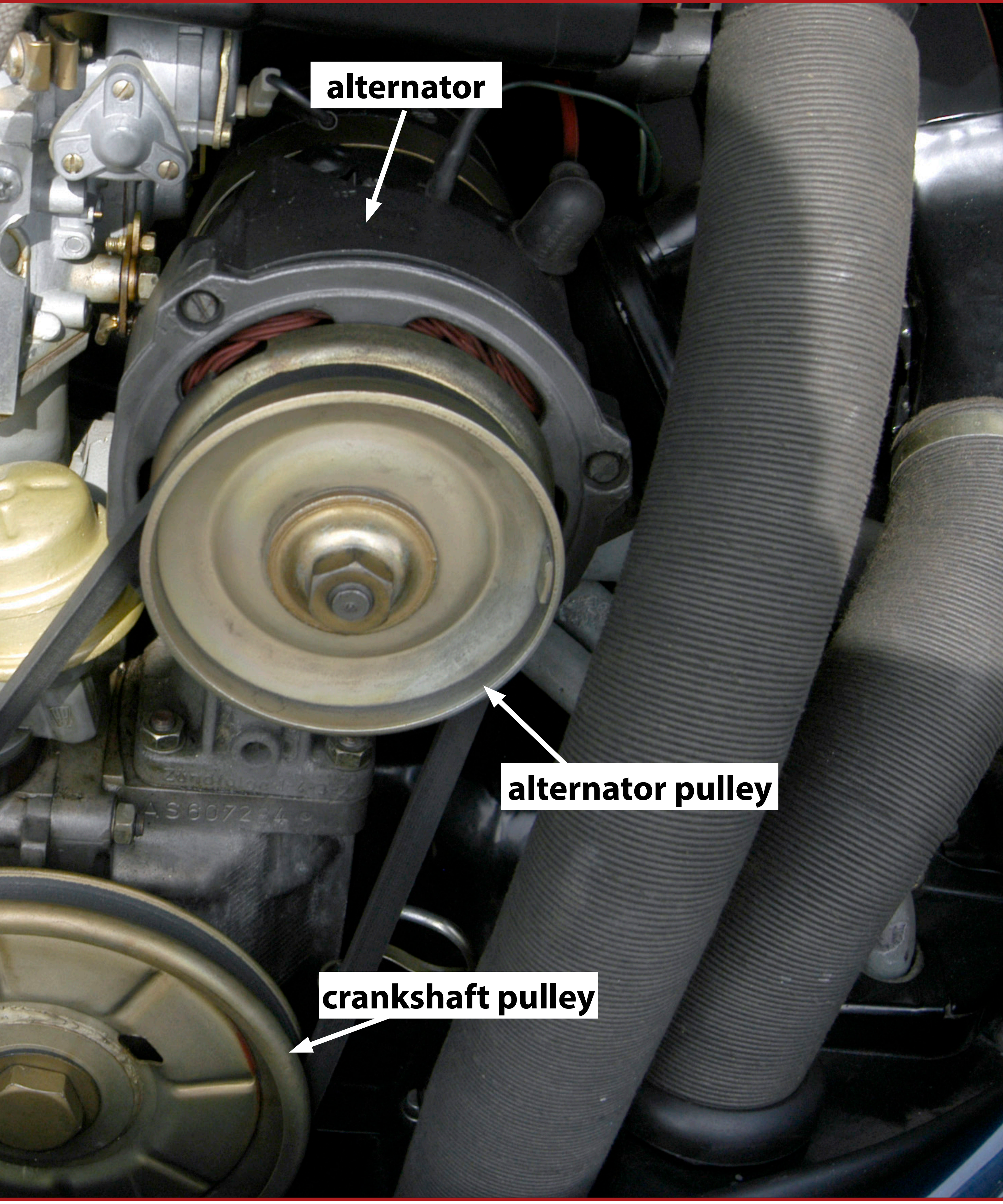


In the picture we show a Type 1 1600 cc engine from a VW 1303. As with the DC dynamo, the ratio of the crankshaft pulley to the alternator pulley is calculated so that the alternator provides enough power to recharge the battery even at idle speed.

The construction of the alternator varies depending on the type of engine. Below we show the alternator of a Water Boxer engine (WBX) as another example.

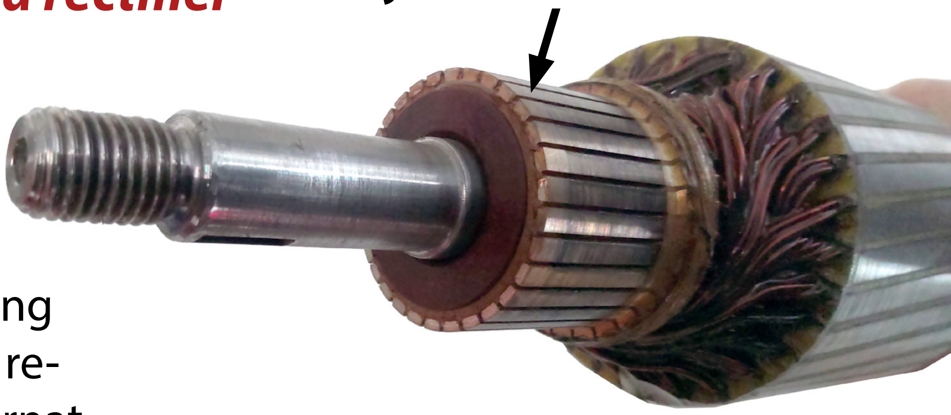


alternator operating principle



The collector becomes a rectifier

dynamo collector



The dynamo's collector (photo at right) had to be replaced with a part that showed less, or no wear. The dynamo's collector, along with the carbon brushes, is responsible for rectifying alternating current (see edition 26).

The collector is a mechanical rectifier, it could be replaced by diodes as early as the 1950s. But the diodes based on vacuum electron tubes (photo right) at that time were still too big, consumed too much energy and got very hot, but above all, they were not suitable to be mounted in a humid environment, nor were they resistant to shock.

vacuum tube diode

Fortunately, the late fifties early sixties saw the rise of "**solid-state**" semiconductor electronics. Still very expensive in the early 1960s, but later in that decades the prices of solid-state components went down, and they became affordable to build into a car.

On page 11 we show one such solid-state rectifier diode, they are barely a few inches in size and can therefore be easily built into the alternator housing.

solid-state diodes

Photo on the right: Solid-state components are insensitive to shock and consume less than their vacuum tube ancestors. They are extremely suitable for use in a moving automobile. The four smaller diodes are rectifier diodes and the larger one on the right is a rectifier diode for higher powers.

The availability of power diodes circa 1963 was the deciding factor at the Bosch company for series production of the alternator.

The mechanical collector of the dynamo is replaced in the alternator by four solid-state diodes, these form a rectifier bridge. With this new arrangement in the alternator, we got rid of the sparking between carbon brush and collector that we had with the old dynamo, resulting in longer life. Thus, the first hurdle was overcome.

Below we show the rectifier bridge built into the alternator. No more moving parts, no more sparks, but lightning-fast semiconductors that convert alternating current to direct current.

rectifier

7

Photo on the right: This is part number 7 of the drawing on page 7. The power diodes are pressed into the cooling metal to better dissipate heat. At the bottom right, we show a loose power diode.

The rotor (field winding)

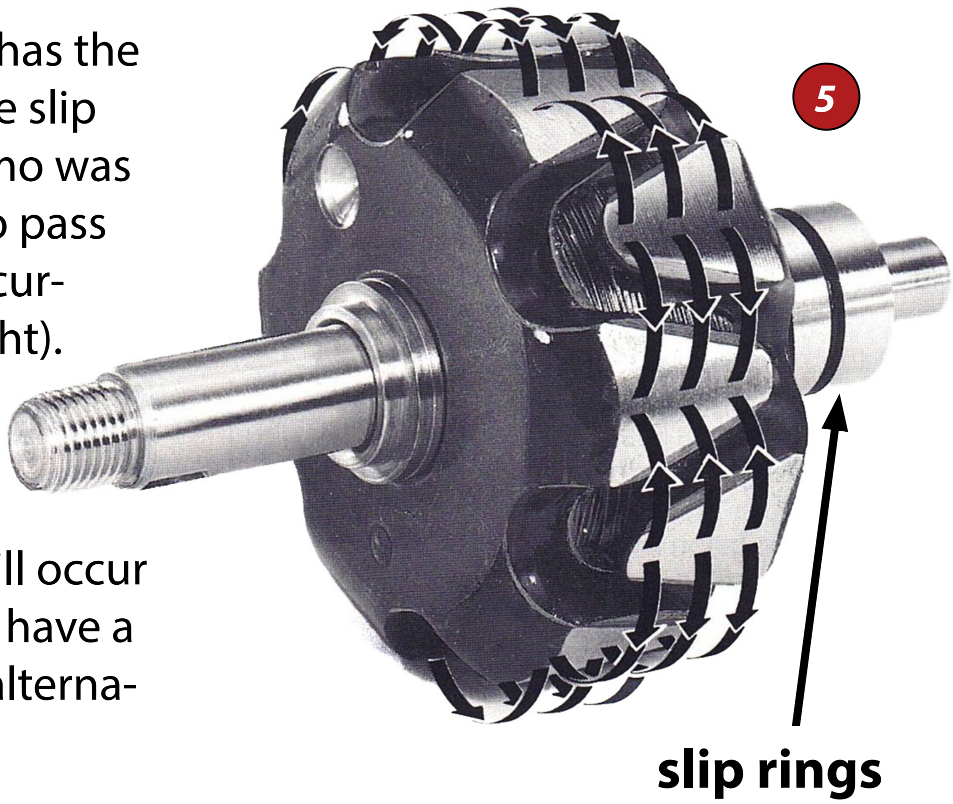
In the DC dynamo, the armature rotates, and the field windings are bolted into the dynamo housing. The field winding is an electromagnet that can be regulated in power by sending more or less current through the windings.

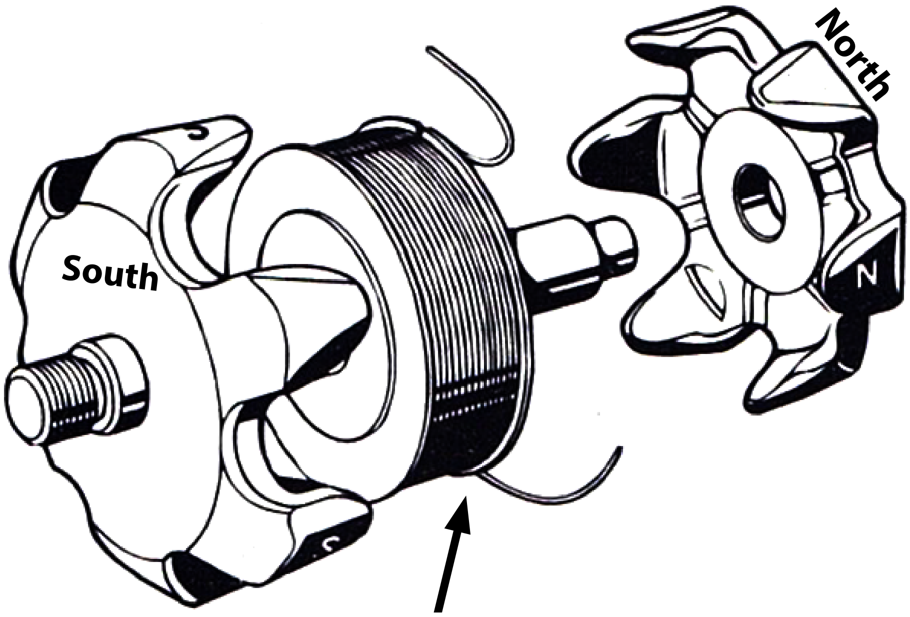
In the alternator, the field winding rotates and the armature is fixed in the alternator housing. The field winding is now called **rotor** and the armature is called the **stator**. The rotor is a magnetic coil or electromagnet.

This change of location has the great advantage that the slip ring, which in the dynamo was the collector, only has to pass the small field winding current (drawing on the right). The copper ring is not interrupted as with the DC dynamo. This means that no sparks will occur and the carbon brushes have a much longer life in the alternator than in the dynamo.

So it is the rotor that will act as a magnet with the alternator.

Rpm: The power of the alternator increases with the rotational speed, which we have previously shown on the graph on page 4. With the alternator too, the aim is to make the rotational speed greater than that of the engine, so that already at engine idle speed the alternator can develop its maximum power.

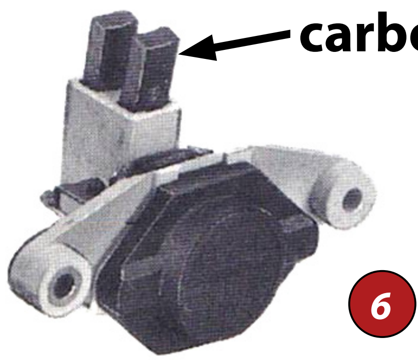




Magnetic field: The rotor contains the magnet poles, which are those claw-shaped metal halves, with the excitation winding (field winding) inside those claws (see drawing on the right). Once direct current flows through this winding, the magnetic field in the rotor is generated. When the rotor begins to rotate, as a result of the rotating magnetic field in the stator windings, a three-phase alternating voltage is generated. Loading the alternator with electrical consumers creates a three-phase alternating current.

Claw pole generators with slip rings enable compact and lightweight construction. The claw halves on the left and right of the drawing form the North and South poles. North and South alternate during rotor rotation to provide the stator with the necessary alternating magnetic field (see edition 26).

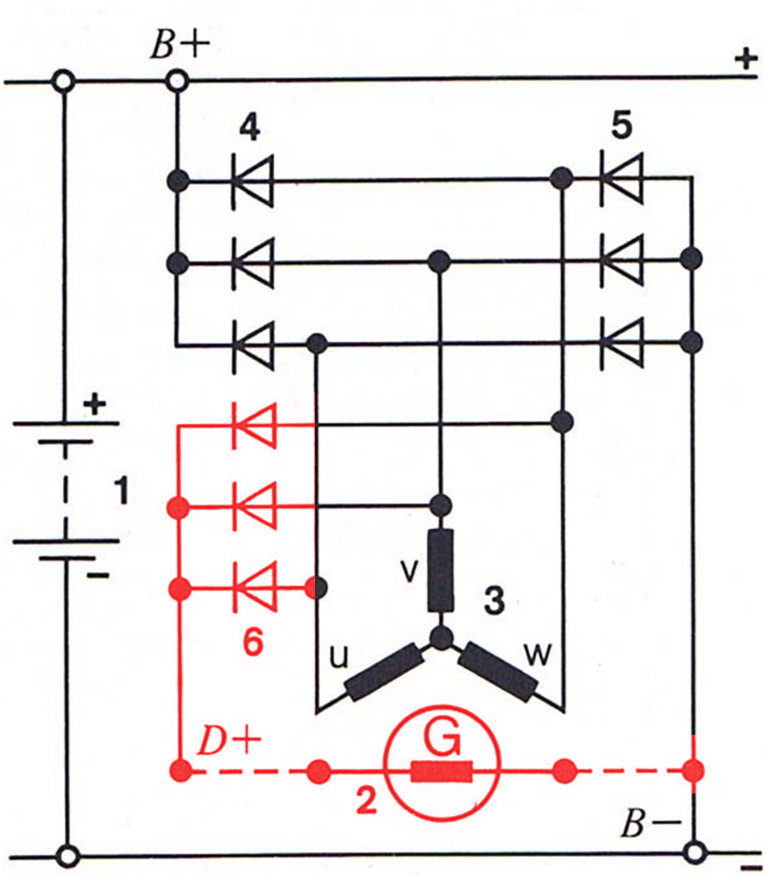
Drawing on the right: the carbon brushes are spring-loaded to push against the copper slip rings with the necessary pressure to supply power to the rotor winding. The slip rings are not interrupted as in the dynamo, so they are less likely to wear out. Unlike the dynamo, in the alternator a small current flows through the carbon brushes and slip rings.



Remanent magnetism:

In the DC dynamo, the remanent magnetism of the pole shoes of the field windings provides enough starting magnetism to get the dynamo going.

Once the dynamo produces current, the current produced is used to amplify the field windings. In principle, the dynamo can operate without a battery.



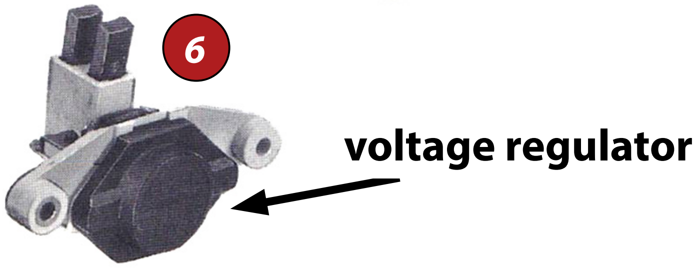
The alternator, on the other hand, needs an external voltage source, namely the battery, to function. The remanent magnetism present in the soft iron core of the rotor is not sufficient to achieve (self-)excitation during starting, or at low engine speed. Unlike the DC dynamo with its mechanical rectifier (the collector), the alternator uses a rectifier bridge with power diodes and excitation or excitation diodes.

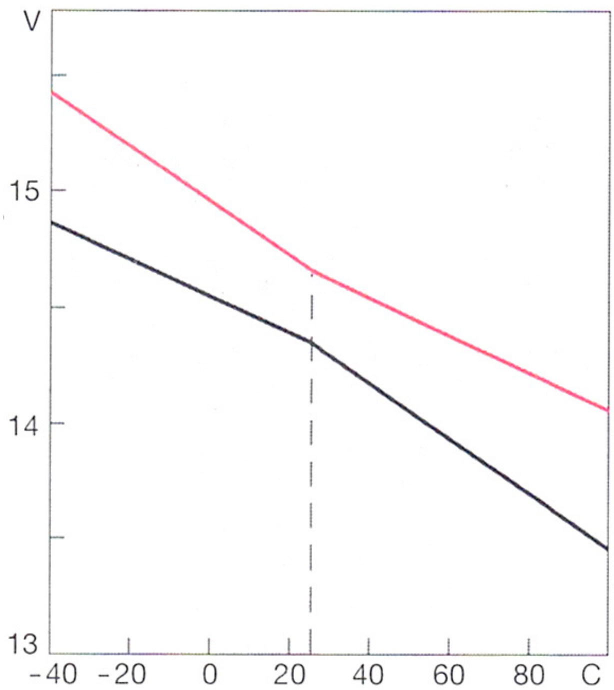
On the left, we show in red how the rotor winding (G) gets its power from the stator windings (U V W). The remanent magnetism of the rotor is not strong enough to cause the diode to conduct, so it will not work without a battery.

How the rectifier bridge works, and how diodes work, we will explain in a future issue.

Cooling:
A coil winding has an electrical resistance, this resistance will mean some loss that will be converted into heat. The heat developed in the alternator must be dissipated to avoid overheating. We now show the built-in fan from the drawing on page 6 separately on the right (number 2). This rotates along with the drive shaft of the alternator pulley and ensures that the alternator is cooled.

The voltage regulator (number 6) built into the alternator, also has temperature control. In high temperatures in summer, the output voltage will be slightly smaller to avoid overcharging the battery, and in winter the voltage is higher (graph on the right shows the allowable tolerance band). We will reserve the operation of the voltage regulator for a future edition, this topic deserves attention in a separate article.



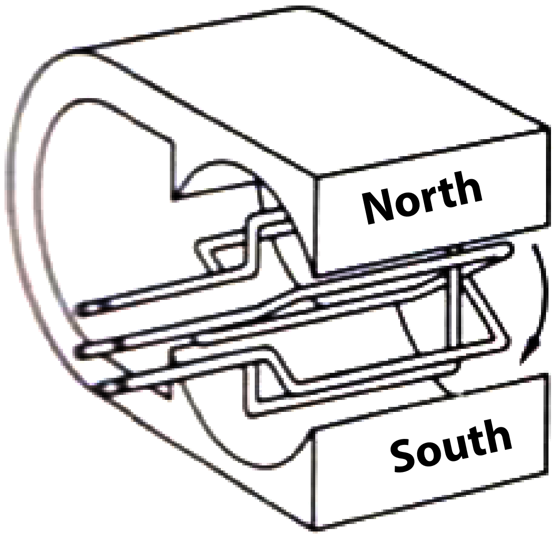


The stator

It is the stator that will generate the charging current with the alternator, with the dynamo it was the rotating armature. The stator is stationary, which explains the name (static), which offers a great advantage for external connection with electrical consumers. This is because it can be done with fixed connections, no rotating collector with carbon brushes and annoying sparks. This removes the maximum current limitation of the DC dynamo. Since the charging current no longer has to pass through a mechanical rectifier (the collector), the current can theoretically become unlimited in size without unpleasant side effects.

The stator of the alternator consists of a three winding, arranged in star to give a three-phase voltage, while the armature of the alternator consists of several windings in series (see edition 26, page 47).

We show in the drawing below a magnet containing three conductors, this is a simplified representation of the alternator's three-phase winding. The permanent magnet in the drawing is replaced in practice by an electromagnet, specifically the rotor, and the three conductors by three stator windings.

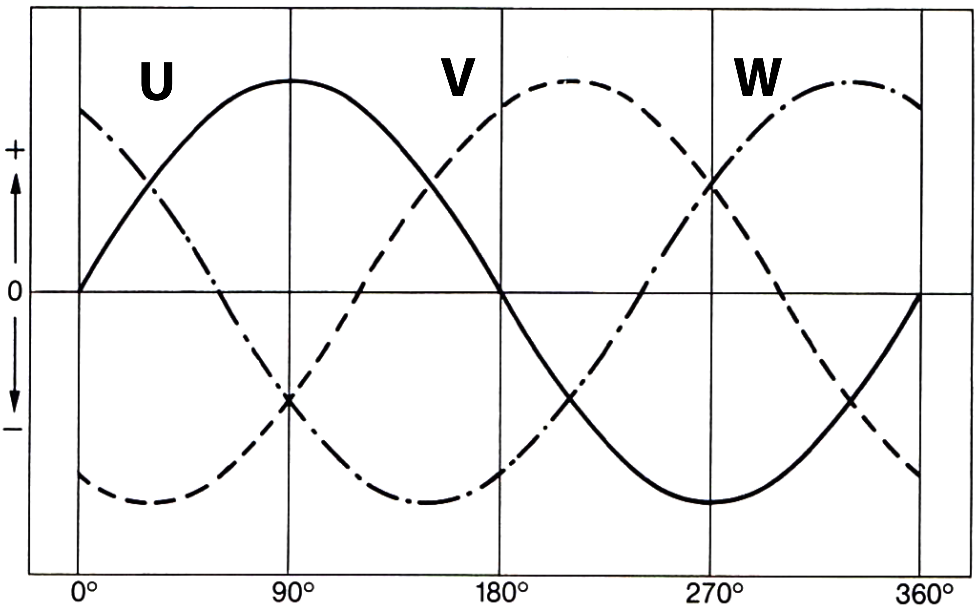


Three voltages, U, V and W, are continuously generated while the alternator is running. The advantage of generating a three-phase alternating current lies in improved efficiency.

On the right we show the stator (number 4) with its three windings. Each winding will have an external connection coded with the letters U, V and W. Thus, the raw output of the alternator is a three-phase alternating voltage.

In the graph below, we show the output voltage for each stator winding. The beginning of the winding is indicated by the letters U, V and W. The three windings are brought together to form one output voltage which is then rectified.

U, V and W are interchangeable, it doesn't matter how you switch them.

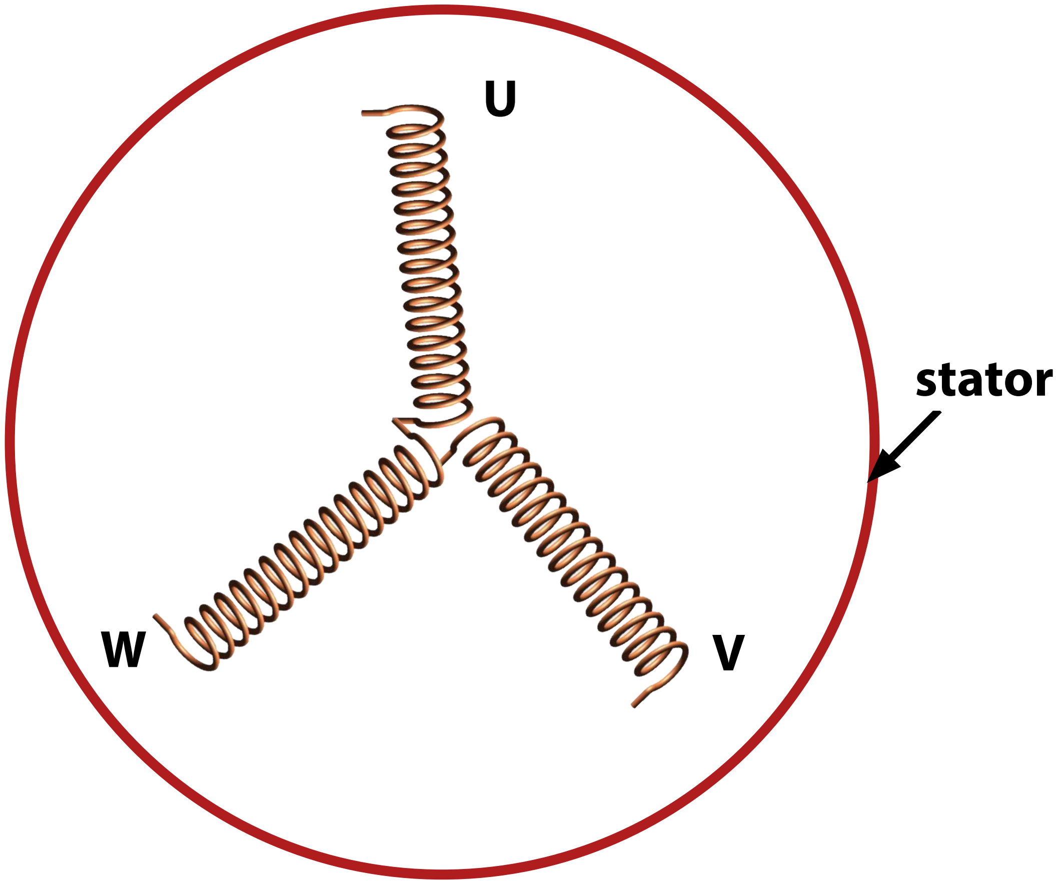


The bringing together is done as with the DC dynamo by connecting the three phases in series, but this time using a star circuit (see page 14).

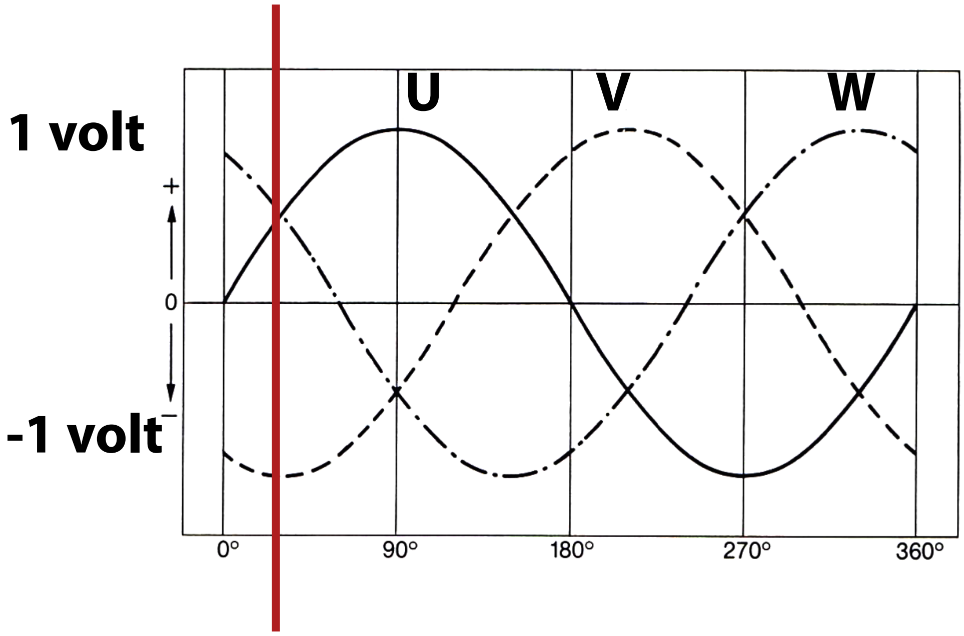
Three output voltages would mean six wires are needed. But, the generated three-phase AC voltage is brought together via a star circuit and then rectified. We show below the principle of a three-phase star circuit. In a star circuit, the ends of the phase windings are connected together, one may do this because the instantaneous values of the three-phase currents are equal to zero at all times.

You can see this in the example graph on page 19. If you draw a vertical line at any instant, you make the sum of the voltage values, and the sum is always zero.

The three windings U, V and W (yellow leads) can also be seen in the picture on page 19, on a Bosch alternator we are overhauling. They are coupled to the diode rectifier inside the alternator housing.

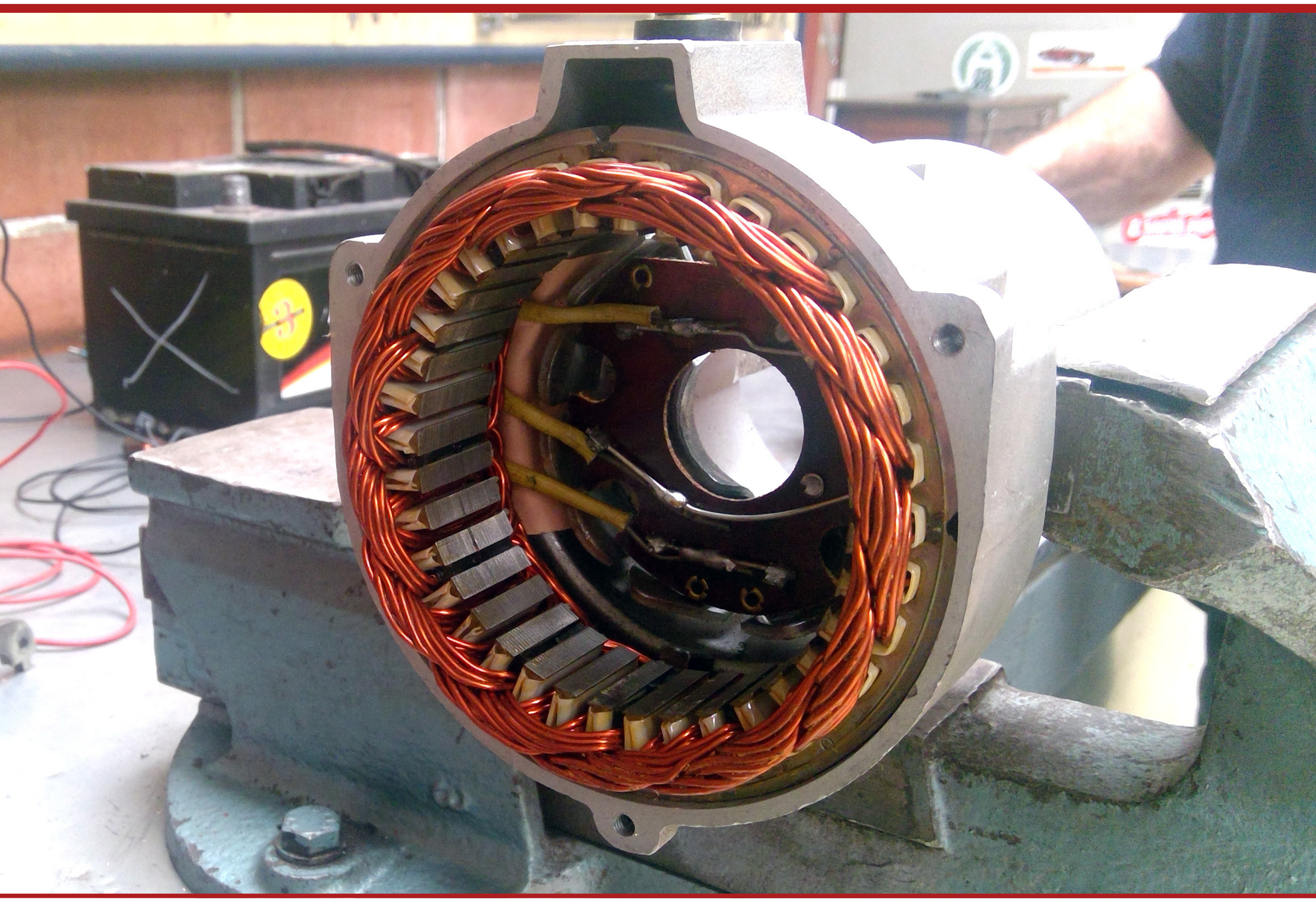


alternator operating principle



U = 0,5 V
V = -1 V
W = 0,5 V

U + V + W = 0V



The Bosch alternator

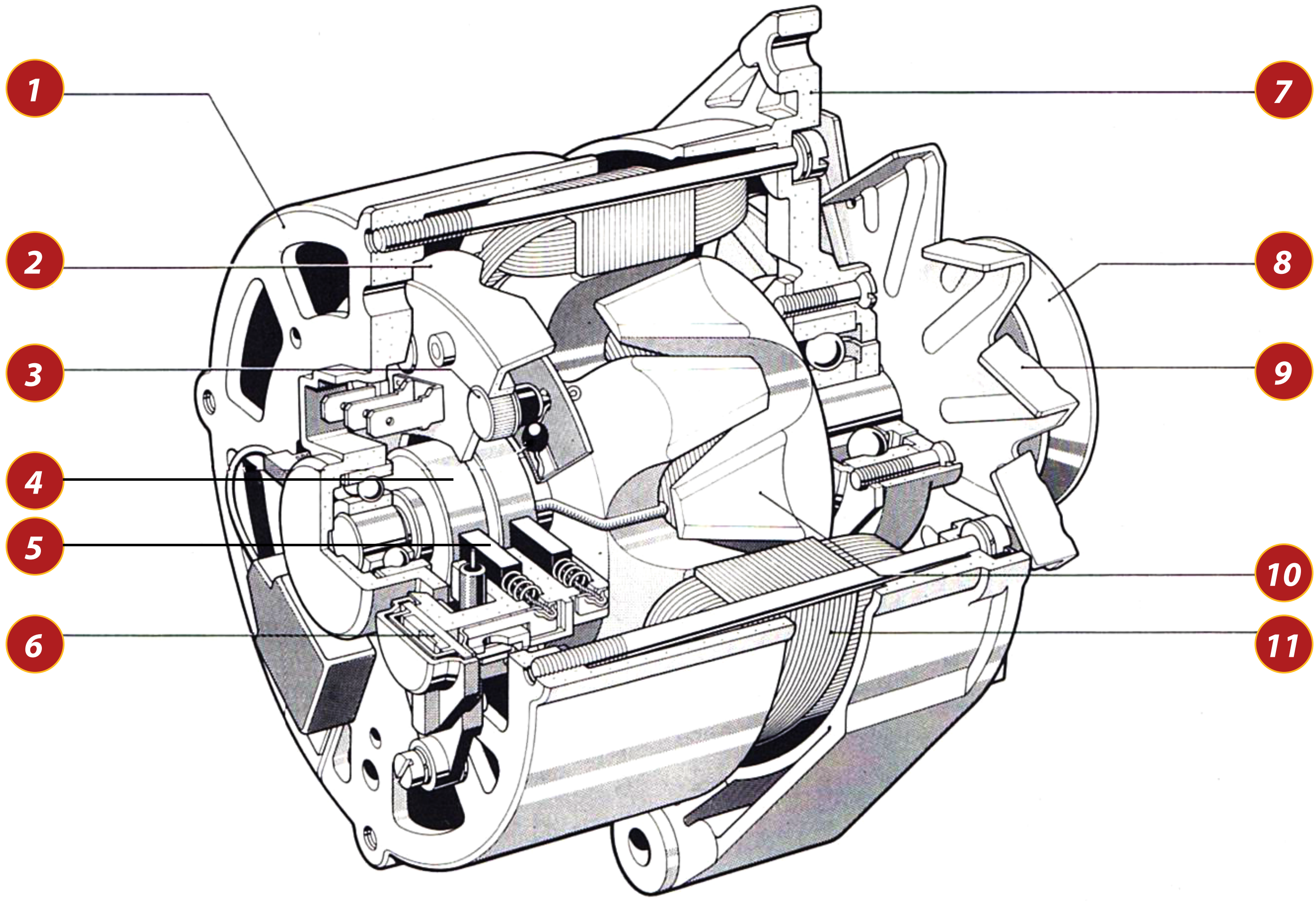
As a summary, we show a drawing of a Bosch alternator, this time with the pulley side at the back on the right (on pages 6 and 7, the pulley side was at the front).

The construction of the alternator is much more compact than that of an dynamo, per kilogram of weight the alternator can produce more current than a dynamo. The advantages of the alternator are listed below. The alternator has a lot of advantages over the direct current dynamo, now does that mean we should upgrade all Volkswagen classic cars equipped with an old style dynamo? Definitely not.

Replacing the dynamo with an alternator affects the originality of the car, and it will add little value if you use your classic VW sporadically. Switch your battery to a trickle charger if you don't use the car much, or only for short trips with lots of idling.

If your Volkswagen has a direct current dynamo, and you want to use it for daily use, and connect additional electrical consumers, then the old dynamo may fail you, it was not designed for modern traffic.

- **higher speed range than the direct current dynamo**
- **can provide power at idle revs**
- **voltage regulator is temperature sensitive summer/winter**
- **weighs less than a dynamo for the same power**
- **compact construction with claw poles**
- **no maintenance required during car lifetime**
- **limits its own current (no current control needed)**
- **can in principle be used in both directions of rotation (pay attention to direction of rotation of the fan)**



1 **alternator housing - slip ring side**

2 **rectifier**

3 **power diode**

4 **slip rings**

5 **carbon brushes**

6 **voltage regulator**

7 **alternator housing - pulley side**

8 **alternator pulley**

9 **cooling fan**

10 **rotor (field winding)**

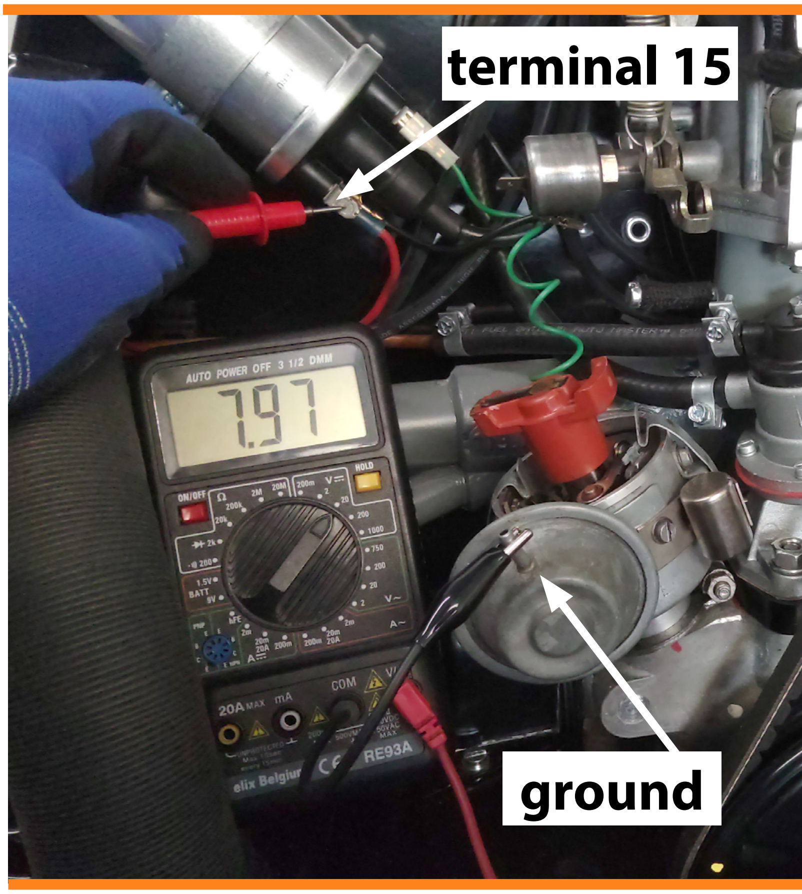
11 **stator**

In the following editions, we will show how to connect and test the dynamo and the alternator.

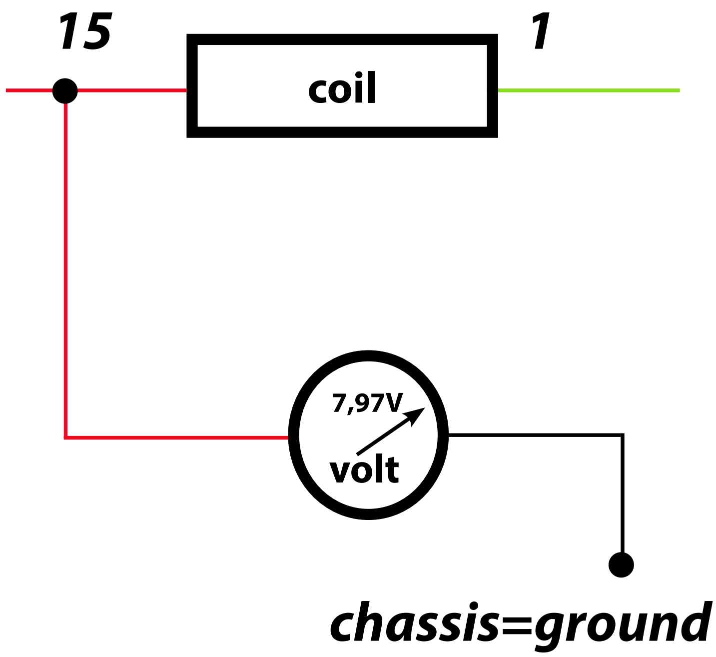
We will also show a total overhaul of both a dynamo and an alternator.

Voltmeter

Everyone has measured electrical voltage before; it's pretty easy. You touch the contacts over which you want to measure the voltage, and the voltmeter indicates the voltage. In the picture on the right, we measure the voltage between the plus terminal (terminal 15) of the ignition coil and chassis (we use the housing of the distributor as ground) when the contacts are closed, that is, when current flows through the primary winding of the ignition coil. The drawing at the bottom shows this measurement schematically.



A voltage measurement is not very invasive, as you can see, not much can go wrong. You do need to make sure that the voltmeter is set to the desired range, up to 20 volts DC in this case. You don't have to disassemble anything, loosen anything, you are an innocent bystander, so to speak.



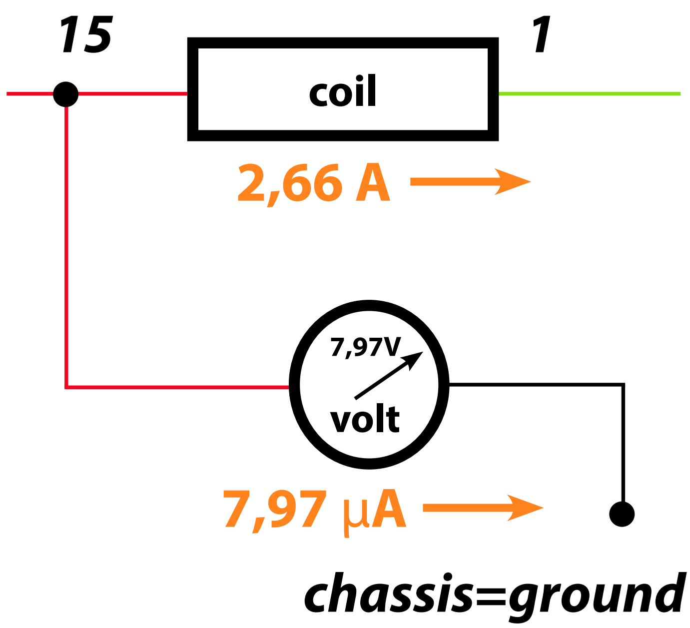
A voltmeter ideally has a very high internal resistance, to consume as little current as possible during the measurement, so that it does not affect the electrical circuit to which it is connected. A professional digital voltmeter will have an internal resistance of 10 M ohms (that's 10 million ohms). A cheaper version will have a resistance of 1 M ohm or lower. The lower the internal resistance the more the voltmeter will affect the circuit and thus the less accurate the reading will be. So invest in a professional multimeter, it will still come in handy in your workshop.

In edition 19 we saw that the primary winding of an ignition coil is about 3 ohms. We calculate the current through the coil at the bottom left of this page, it should be 2.66 A. The resistance of our voltmeter is 10 M ohms, so the current through the voltmeter will be virtually zero (7.97 µA to be exact). Thus, the voltmeter has practically no influence on the operation of the electrical circuit. Because the voltmeter has no influence on the measurement, due to its high resistance, this is a measurement with little risk.

$$I_{coil} = U / R$$

$$I_{coil} = 7{,}97V / 3\ ohm = 2{,}66\ A$$

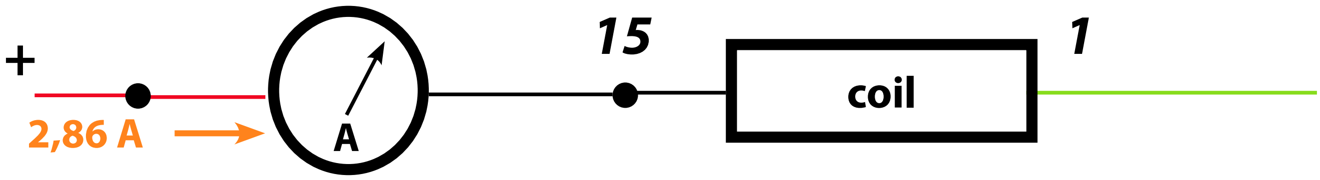
$$I_{voltmeter} = 7{,}97V / 10^{+6}\ ohm = 7{,}97\ \mu A$$

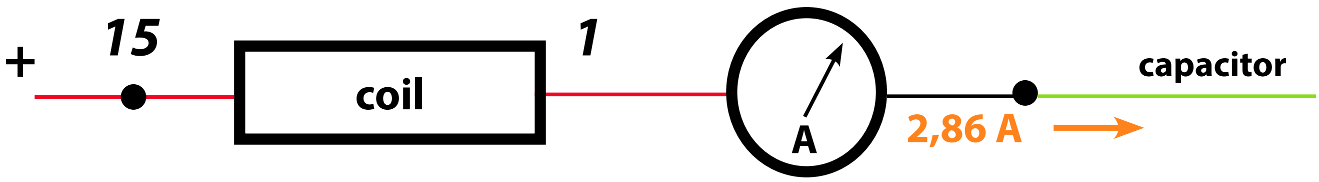


Ammeter

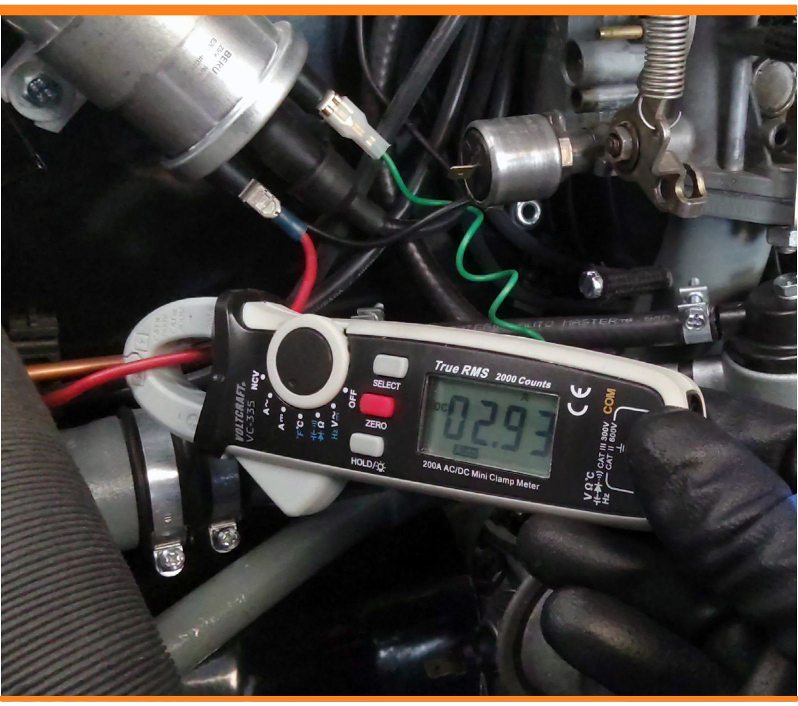
Measuring current with an ammeter (amperemeter) involves much more risk. To measure current, you must interrupt the circuit through which the current flows. The ammeter must be connected in series, as we show in the drawing below, we show how to measure the current flowing through the primary winding of the ignition coil. You can connect the ammeter in front of the coil, between terminal 15 and the plus terminal (as in the picture on the right), or between terminal 1 and the green lead of the capacitor, it doesn't matter, the current in front of, or behind the coil, is the same.

The measuring terminals must be switched into a different connection in the multimeter to measure current than for measuring, for example, a resistance (ohmmeter) or a voltage (voltmeter) or mA (milliampere).





We had calculated that the current should be 2.66 A (with a 3 ohm coil), we measure 2.86 A. Of course, the coil is not exactly 3 ohms, the current will also vary with the heat of the coil.
Ideally, an ammeter will have a resistance value of 0 Ω so as not to affect the reading, but in practice any ammeter will have a small resistance. Professional ammeters will have a much lower resistance and thus have much less influence on the electrical circuit.



The main problem with this ammeter is that you have to **interrupt the circuit**, to connect the ammeter in series. For measuring the current through the primary winding, this is not too bad. Just disconnect terminal 15 and connect the ammeter between the terminal and the plus cable. But when there are no terminals, or they are hard to reach, then a current measurement with a classic ammeter is difficult. Cutting cables to measure current is not a good idea, and far too invasive.

Therefore, that a current clamp is a better solution (photo left). This type of ammeter does not affect the circuit to be measured, it measures the magnetic field around the conductor (induction principle, see edition 26).

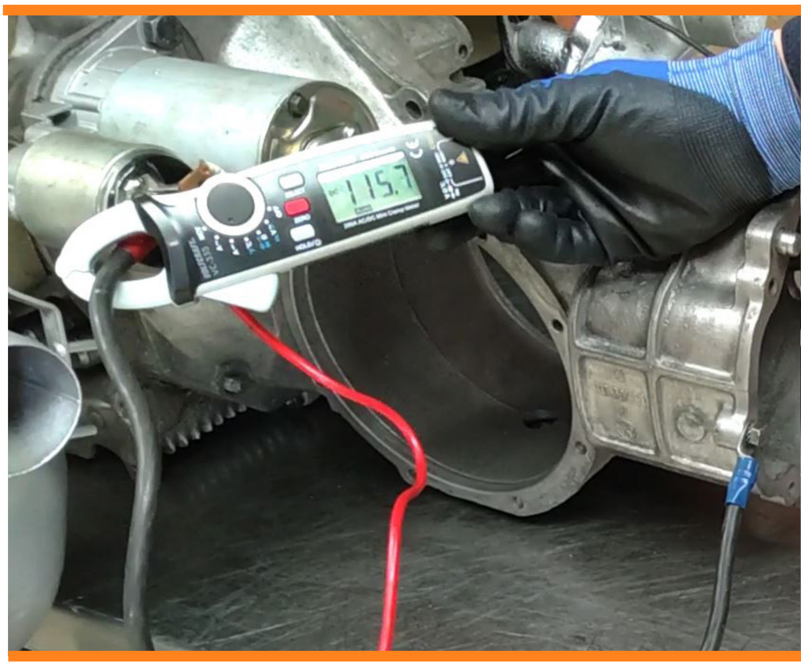
With the current clamp we measure a direct current of 2.93 A through the primary winding of the coil (photo left) .

#80 Technical

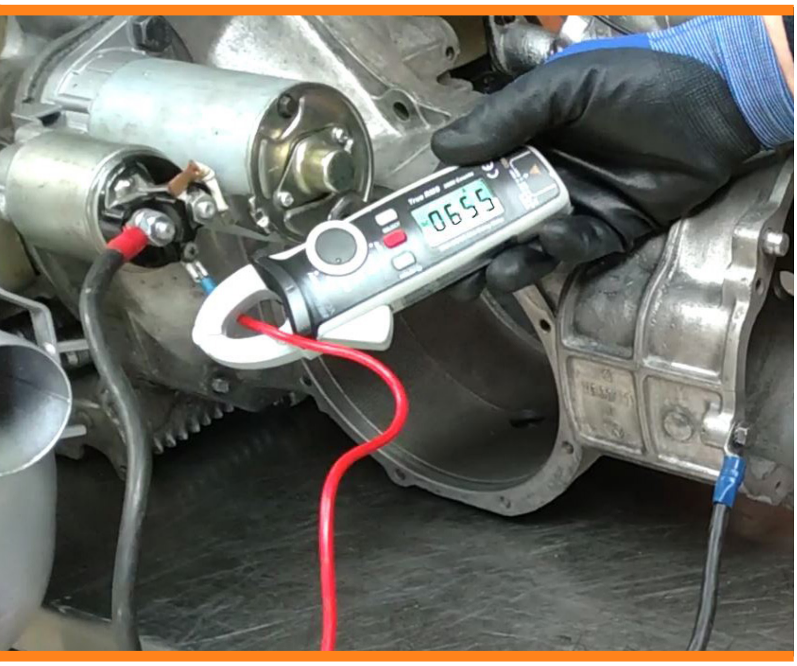
Another problem that arises is that **you don't always know how much current to expect**.

A typical ammeter can measure up to a maximum of 10 A or 40 A, for example. If the measured current is higher than allowed, the fuse of your ammeter will blow. Some ammeters have an electronic current limiter, then you just see an error message displayed. And, this all happens while the ammeter is part of your car's electrical circuit. So, not a good idea.

When measuring the ignition coil, we had done some preliminary work, and we knew that the current would be somewhere around 3 A, 4 A maximum. Our ammeter can go up to 20 A, so no problem. But if we don't know how much current flows through a cable, then it's best to keep a set of spare fuses for the ammeter within reach.



If we want to measure the current flowing through the armature of a starter motor, most ammeters will not be suitable. A normally loaded starter motor, for example while starting an engine that has already warmed up (the engine oil is then very thin), will draw between 100 A and 150 A of current (115.7 A, see photo above). A heavily loaded starter motor can draw up to 400 amps of current from the battery. Connecting an ammeter in series with the starter motor power cable is not a good idea.



If you want to measure an electrical current at your classic VW, we recommend doing so with a **current clamp**. With a current clamp, you don't need to interrupt the electrical connections, you place the current clamp over the cable whose current you want to know, that's all. No damage to the terminals or cables, no impact on the operation of your electrical circuit at all. The picture on page 26 shows the starting current of our starter, 115 A. We also measure the current flowing through the contact switch and the solenoid, the current for this starter is 6.55 A (photo top of page).

Switch your current clamp to direct current for this measurement. Measuring an electrical voltage most enthusiasts have already done. Measuring a current through an electrical conductor is a little trickier. Don't risk damaging your wiring harness, always use a current clamp to measure a current.

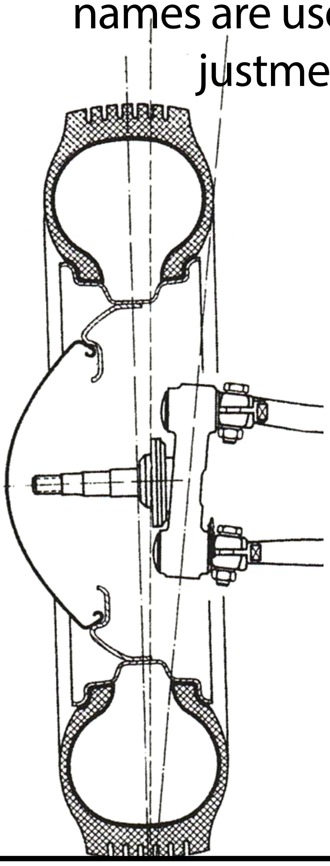
We test the starter with the engine on the workbench, you will need to build a tool for this as shown in the pictures, since the starter of our VW is supported in the gearbox. Never use the starter loose on the workbench, it will seriously damage the armature.

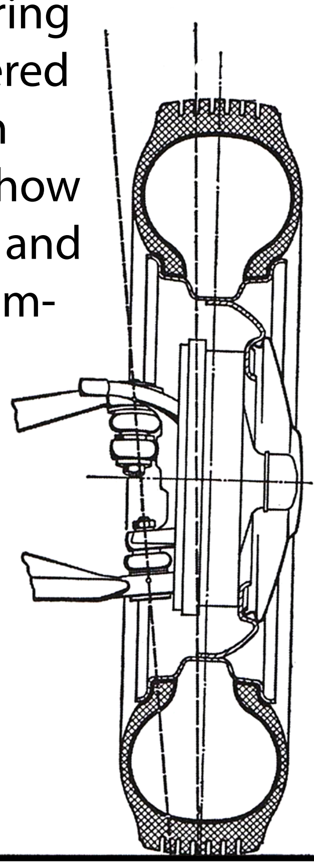
Front axle

Introduction

This series on wheel geometry aims to provide the owner of a classic Volkswagen with information on the importance of wheel geometry, as well as guidelines for the specialist who will adjust the wheel geometry. In the previous two editions, we provided an introduction. We recommend that the reader study the contents of both articles carefully before getting started with measurement and adjustment. It can be somewhat confusing as different names are used for the same adjustment.

During or after a restoration, or before driving to a specialist, you can take some measurements yourself to verify that the wheel geometry is within acceptable values. An exact adjustment can then be done at the tire specialist with precision tools.
In this edition, we will explain how to measure front axle wheel geometry, and what the values are for each type of classic VW. Camber Angle (Wheel Camber), Toe and Caster are discussed in this edition. Measuring the rear axle is covered in edition 28, and in edition 29 we will show how to adjust front and rear axle wheel geometry.

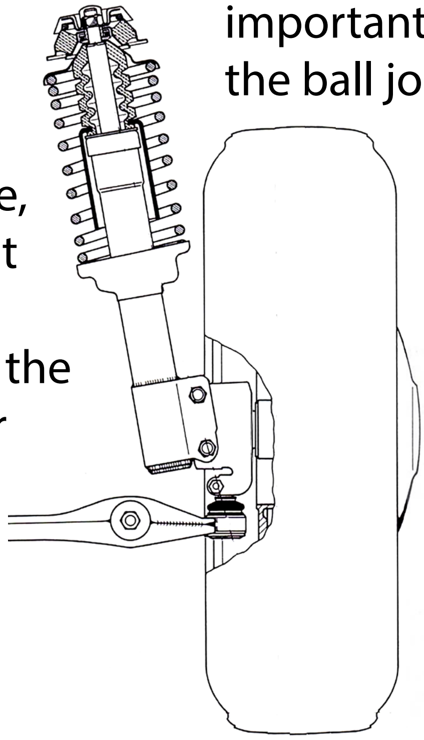




On the left is the old type front axle with King Pins, on the right is the younger version with ball joints. On the next page, we show the MacPherson front axle.

Preparations

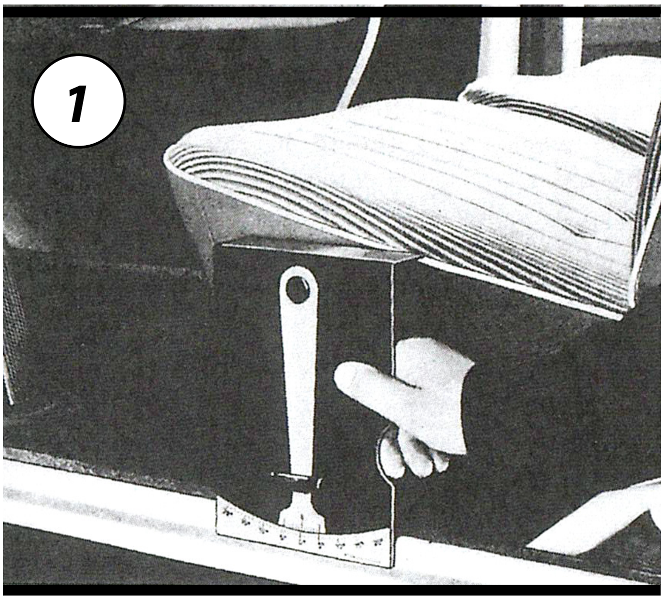
In previous editions we have shown both the old type of front axle with King Pins, the newer type of front axle with ball joints, and the more modern MacPherson. It is important to know which type of front axle you have, because the measurement and adjustment of wheel geometry can depend on the type of front axle. The rear axle is always with torsion bars, its adjustment does vary over the years.

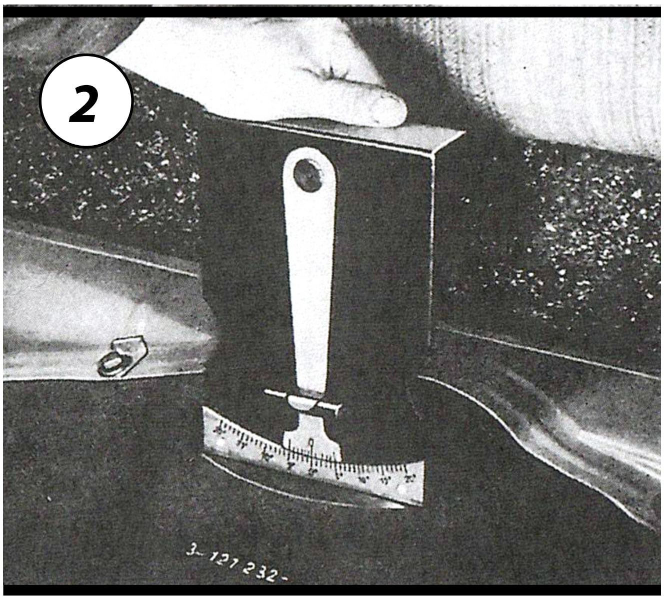


Since alignment (geometry) is sometimes about tenths of millimeters, the preparations mentioned below are extremely important. A minimal play on the ball joints, for example, will make the geometry adjustment impossible, or at least inaccurate. Before measuring the wheel geometry, you should take a number of precautions:

- mount the rims and tires that will be used on the car
- the tires are at the correct pressure and all four are in good condition (not bent)
- the car is completely empty, and the fuel tank is full to half-full
- the steering parts are in good condition and correctly adjusted
- the front torsion springs/leafs are in good condition
- the rear torsion bars are correctly adjusted and have been used for at least 500 km
- front wheel bearing play is properly adjusted
- King Pins, ball joints or MacPherson joints are free from unwanted play
- all lubrication points of the wheel axles are lubricated with sufficient grease
- the front wheels are in the straight-ahead position
- drive the car on level ground and make sure it is perfectly level

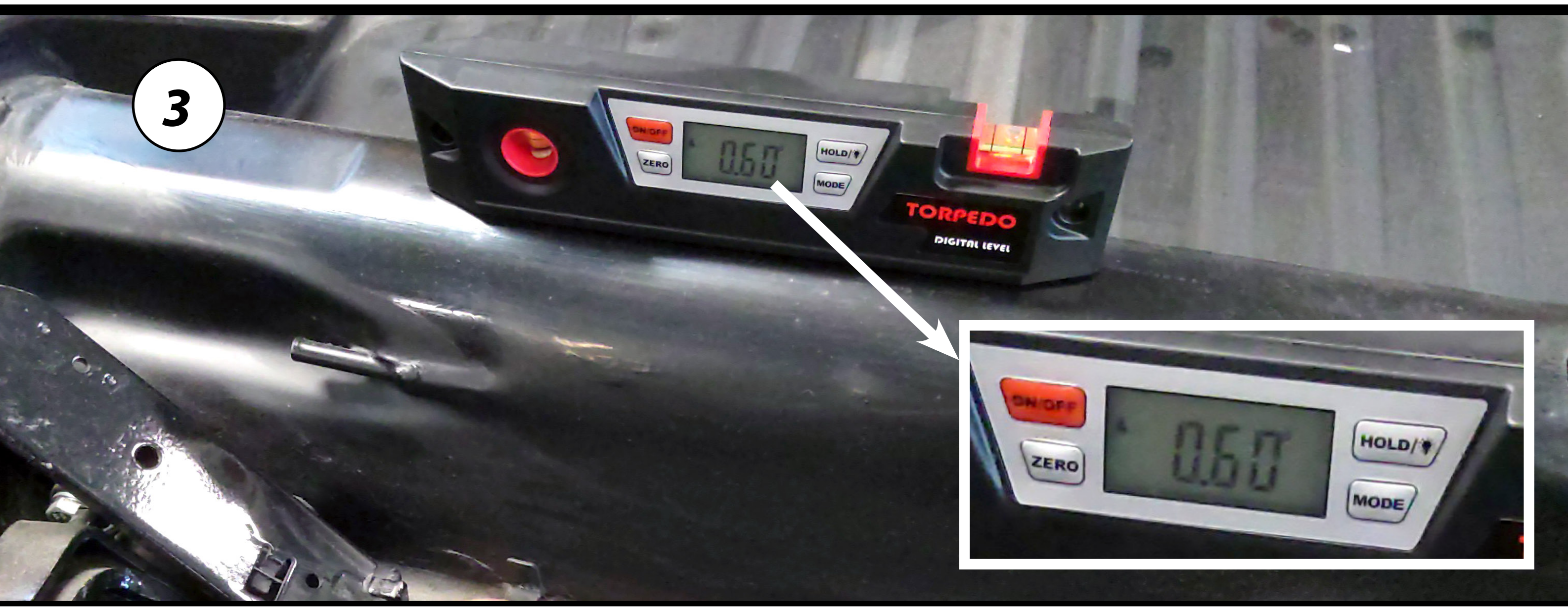
Level - with front wheels in straight-ahead position





One of the conditions for making the measurements is that your VW's chassis is perfectly horizontal. In the VW workshop manual, they do this with a special protractor (photos above, VW 245a tool).

You can also do this with a modern and very affordable version, the digital level (photo below). This type of level is accurate to within 0.05°, is not expensive at all, and you can use it later for other applications.

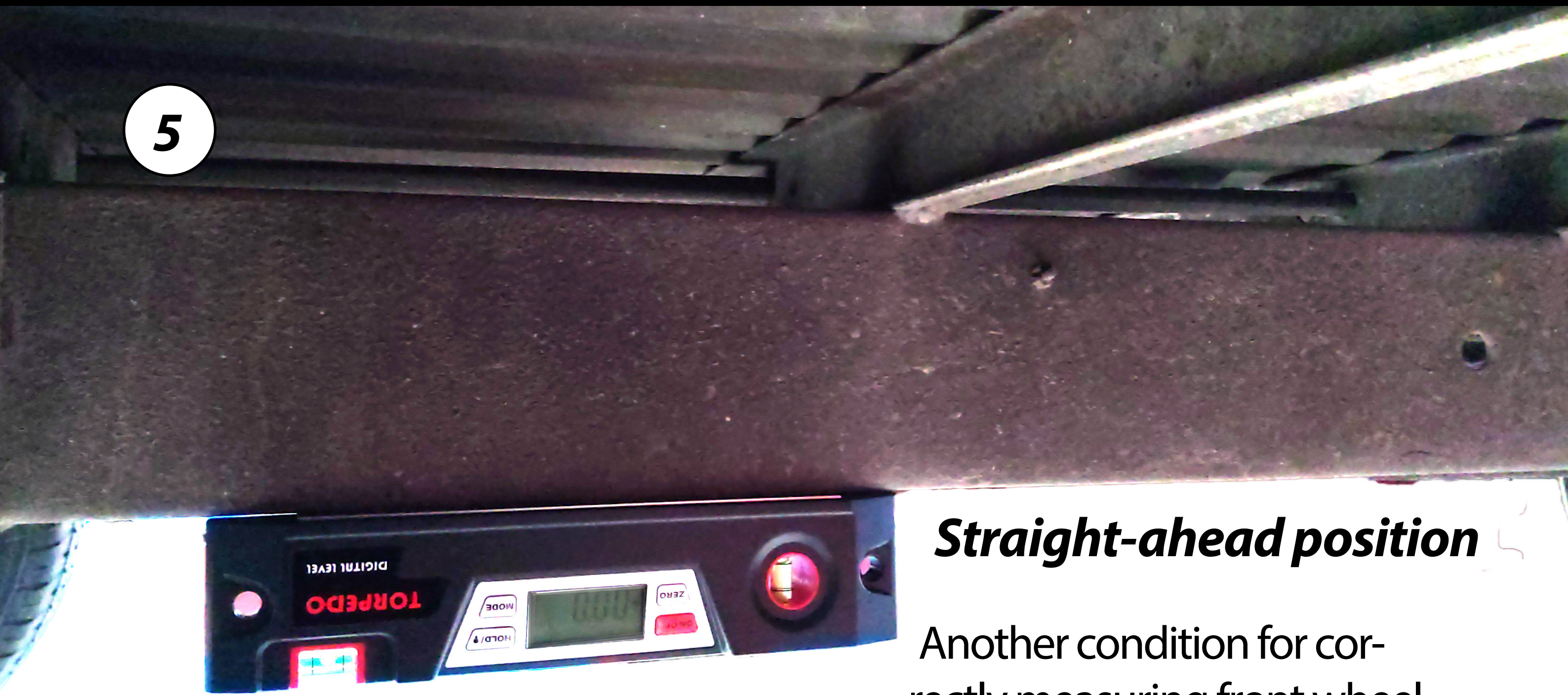


measuring wheel geometry

You must measure the level in both the longitudinal and transverse directions. VW recommends measuring in the longitudinal direction on the heater channel (door step, photo 1). The older books measure on the chassis tunnel (photo 3), but that can sometimes be tricky when the interior is tarred for sound insulation and a thick carpet. Whether the car is level in width (transverse direction, photo 2 and photo 4), measure on the rear tunnel, under the rear seat.

We are using our digital level on the tunnel of a VW Beetle. The level should indicate 0° degrees. Here we see 0.60°, with an upward arrow on the left (photo 3), meaning the front end should be 0.60° up.
In the transverse direction, the right side is 0.30° too high (photo 4). Try to position the car as close as possible to 0° with wooden plates under the wheels, for example. As enthusiasts we try to have an idea if the wheel geometry is OK, an exact measurement and adjustment will still have to be done at the tire specialist. So, aiming for almost 0° is good enough.

Front axle



Straight-ahead position

On the VW Bus, you can place the level at the bottom on the left (photo 5) and right chassis beam, taking turns, to measure the level in the longitudinal direction. For the transverse direction, place the level against the front axle tube (photo 6).

Another condition for correctly measuring front wheel geometry is that the wheels are in the straight-ahead position. You can achieve this by pushing the car forward; the front wheels should turn automatically into the straight-ahead position. If the front wheels do not turn into straight-ahead position by themselves, then the wheel geometry is seriously wrong.

Degrees and minutes

The workshop manuals indicate angles in degrees and minutes. Not to be confused with decimal degrees as our digital level indicates. You will therefore have to make a conversion when looking up Camber angle in a manual, for example. The most common way to indicate an angle is as follows:

10 degrees 40 minutes 10 seconds

or with symbols

10° 40' 10"

with

1° = 60' = 3600"

If you want to convert the angle 10° 40' 10" to decimal degrees, you can use this formula:

10° + 40'/60 + 10"/3600=
10° + 0,67 + 0,00278 = 10,67°

If we apply this to, for example, the Camber angle of the front wheels of a 1950 VW Bus, namely the angle is 0°40' with a permissible deviation of +/-30', the value of the Camber angle may then be a minimum of 0°10' and a maximum of 0°70', translated in decimal degrees:

ideal 0°40' = 0,67°
maximum 0°70' = 1,17°
minimum 0°10' = 0,17°

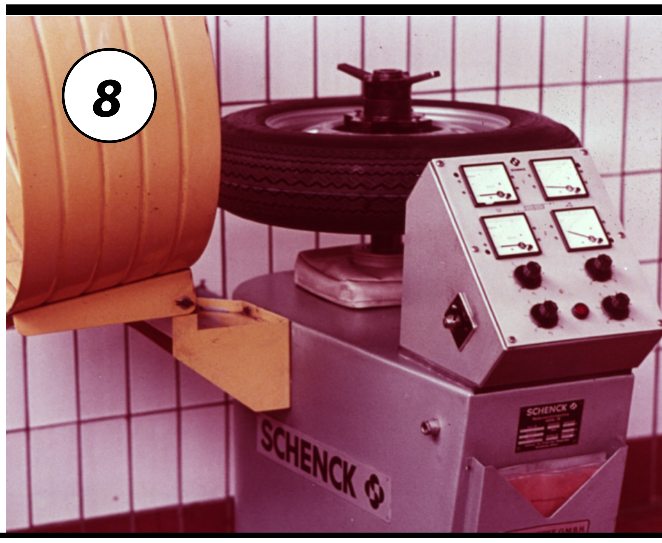
So always pay close attention to whether the angle is given in degrees and minutes, or in decimal degrees. If math is not your strongest subject, you can find a conversion tool from degrees and mintutes to decimal degrees online.

#81 Front axle

Balancing

When you mount tires on your rims, those rims with tires need to be balanced. Tires (and rims), are not perfect and will not have the same weight all around. On tires, a yellow circle is applied (photo 7) to indicate where the heaviest place is (on the other side of the dot namely), to mount the tires correctly to have as little imbalance as possible. The nipple is ideally mounted on the side of the yellow dot. The remaining imbalance is eliminated with small weights glued or nipped onto the rims. Sometimes a red dot is also present, which indicates the place where the tire is thickest, i.e. heaviest.

We will talk about tires and rims in a later edition, then balancing will be discussed in detail (photo 8: tire balancer from VW course slide). Once a rim and tire are balanced, it will rotate evenly without vibrating. An unbalanced or poorly balanced rim/tire combination can be recognized by the vibration of the steering wheel, vibration of the entire car and less grip. Vibration can also have other causes such as worn or damaged tires, damaged steering rack or suspension components.



Alignment = Wheel geometry

Alignment is what we will explain in this article (not to be confused with balancing), it is the adjustment of Wheel Camber (Camber angle), King Pin Inclination (KPI), Caster or Toe, in short, the adjustment of wheel geometry. This does not have to be done at every tire change, or at regular intervals, but rather when you fit a different type of rim or tire size, or add or remove wheel spacers, or raise or lower the car.

Changing the rim/tire combination changes the wheel geometry (see edition 25 and edition 26). Also, when you install a different type of front or rear axle, the wheel geometry must be changed, or when you replace the suspension arms, King Pins or ball joints.

After an accident, a severe shock to the suspension (driven into a deep pit) the wheel geometry should be checked to be sure.

After a total restoration, it is imperative that the car be aligned by a specialist. Wheel geometry should also be performed when any of the following phenomena occur:

1. **vehicle pulls to one side**
2. **unusual tire wear**
3. **steering wheel pulls to one side when driving straight**
4. **tires scuffing on the road**

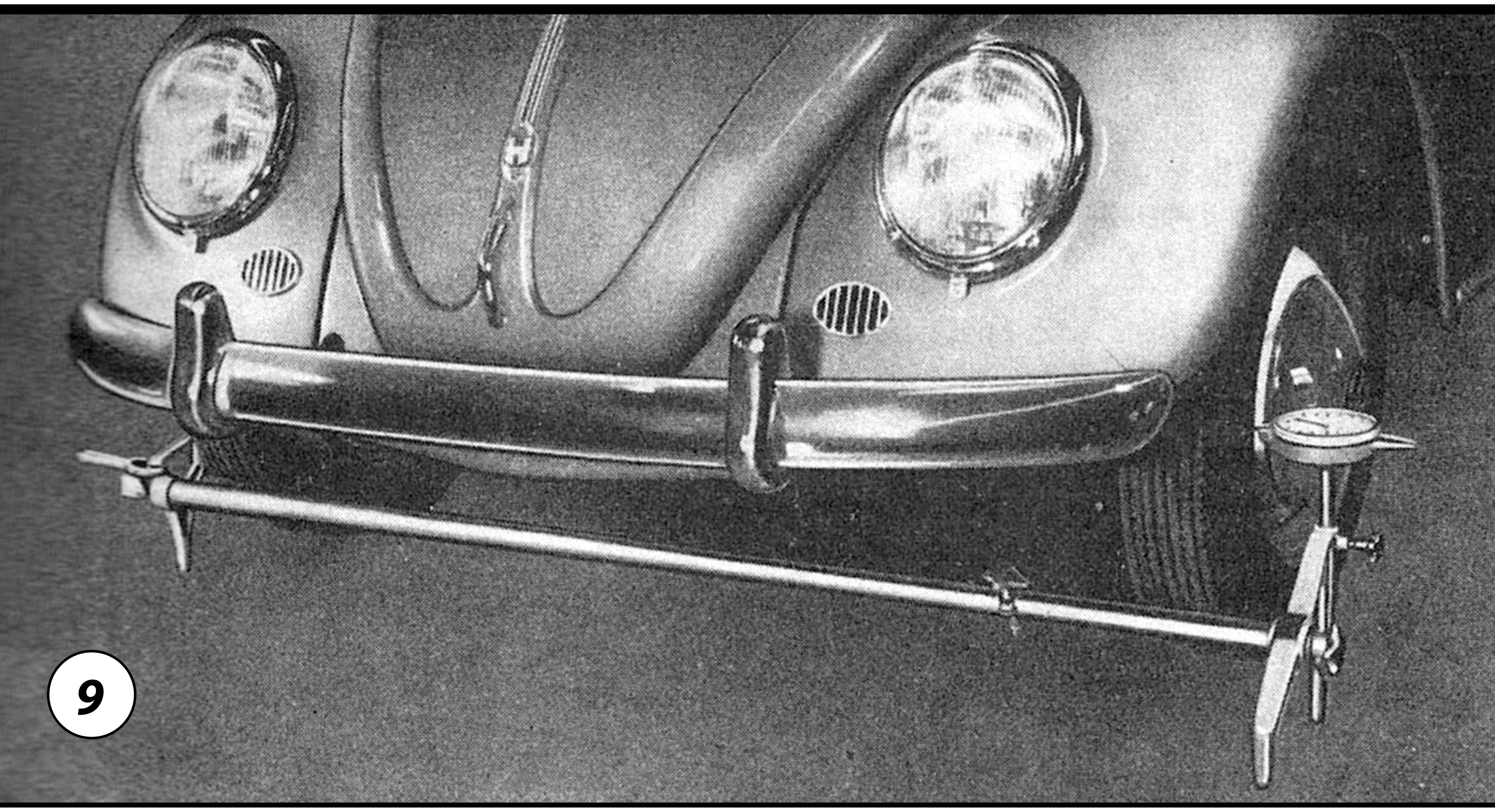
Not all discussed settings of wheel geometry can be adjusted, it will depend on the type of suspension and year of construction.

Measuring and adjusting wheel geometry is possible only when a number of conditions are filled in. We have listed the conditions on page 29. Make sure those conditions are completed before you start this job.

Measuring tools

Because some settings are about tenths of a degree, it is difficult to do so with DIY tools. Tire specialists are equipped with modern precision tools to adjust wheel geometry, but unfortunately they no longer always have the necessary knowledge of vintage cars and certainly do not have the adjustment data of a 60-year-old automobile in their system.

Volkswagen advised its franchisees with workshop manuals and special manuals with guidelines on how to set up the workshop and how to use the special tools. Technicians had to be retrained regularly as new models, new tools and new techniques came with them. Below we show adjusting the Toe-In as it was explained in the VW workshop manual.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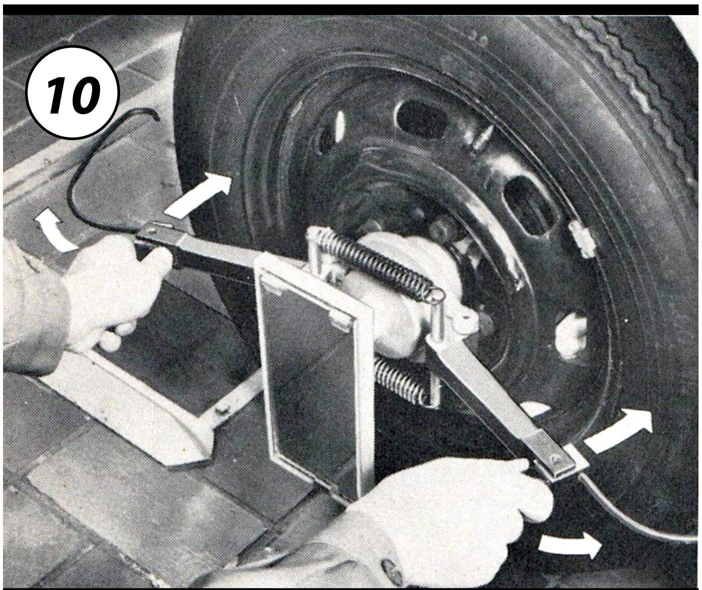
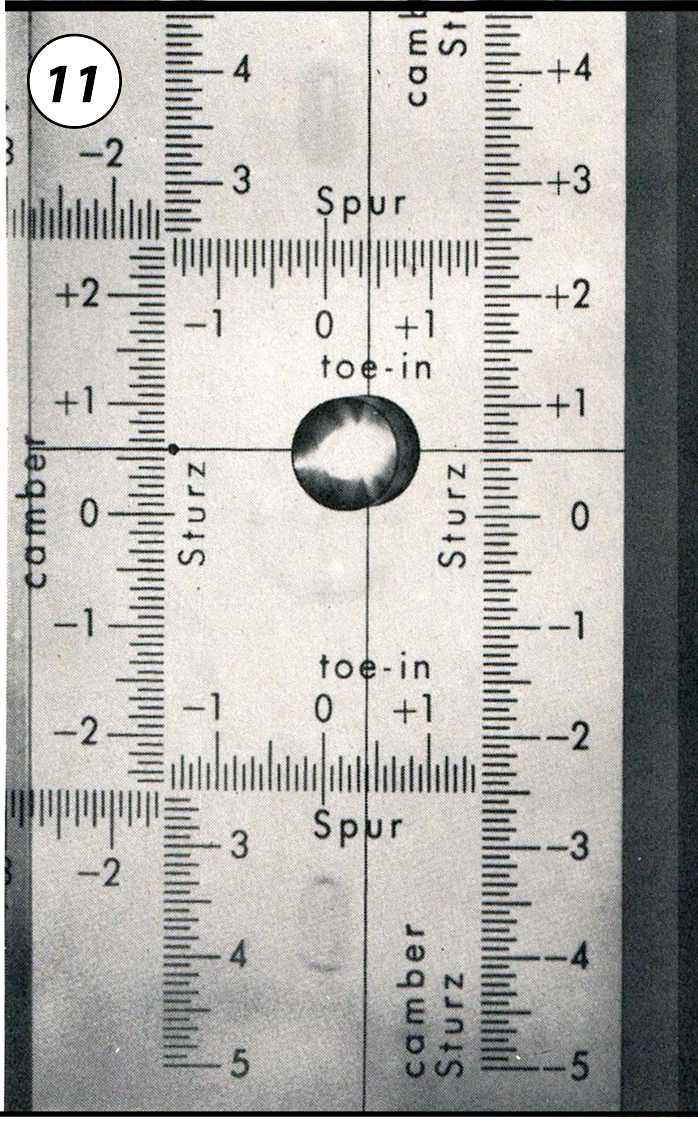
On the right (photo 10) we show the device with mirror system that was used by Volkswagen to adjust the Camber angle and Toe-In. Photo 11 shows the scale on which the measurement is projected, both Toe-In and Camber could be read on it. Chances are very slim that any enthusiast has this tool in their workshop, but, don't give up too soon. Of course, it is always more fun for the hobby if you can measure some things yourself.

We will therefore advise on affordable tools you can buy to give your VW classic a basic setting. After all, you can get a long way with a protractor and a level, just enough, to drive up to the tire specialist to have the precise adjustment done there.



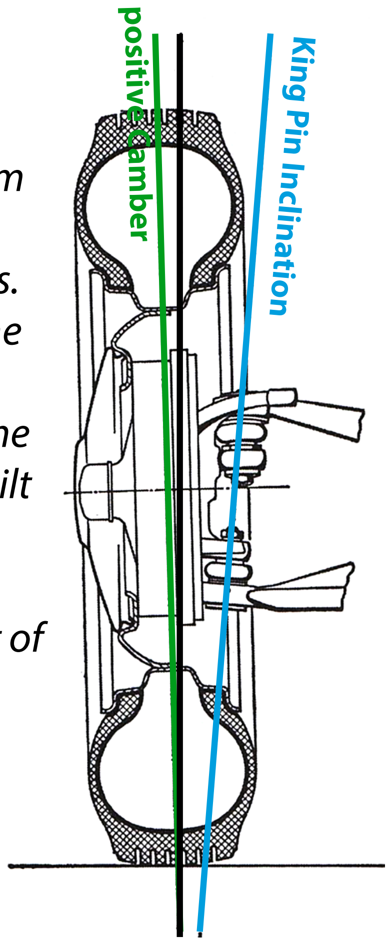


Measuring wheel geometry

Camber Angle

We start with the Camber Angle of the front wheels. When we measure the Camber, we are actually measuring the tilt of the wheel and the tilt of the King Pin. The tilt of the King Pins is the King Pin Inclination (KPI). KPI is partly determined by shims on King Pins, on ball joints front axles and MacPherson, it is fixed.

This is a drawing from edition 25 of a front wheel with ball joints. The tilt or angle of the wheel is the Camber angle. It is actually the combination of the tilt of the wheel plus the King Pin Inclination (KPI), which is the tilt of the King Pins.



CAMBER FRONT WHEELS	YEARS	Front axle type	Camber Angle	Deviation
Type 11, 14, 15	1952-1957	king pins	0°40'	+/-30'
	1958-1960	king pins	0°40'	+/-30'
	1961-1965	king pins	0°40'	+/-30'
	1966-1969	ball joints	0°30'	+/-20'
	1970-1979	ball joints	0°30'	+/-20'
	VW1302/1303	MacPherson	1°	+20' -40'
Type 2	1950-1962	king pins	0°40'	+/-30'
	1963-1967	king pins	0°40'	+/-30'
	1968-1979	ball joints	0°40'	+/-15'
Type 3	1967-1970	king pins	1°20'	+/-10'
Type 4 (VW411/412)	1971-1974	MacPherson	1°10'	+25' -30'
VW Golf/Jetta/Scirocco	1974-1984	MacPherson	0°20	+/-20'

To measure the Camber Angle, the following conditions must be met:

- **chassis is level**
- **wheels are on the ground**
- **car is completely empty**
- **front wheels in straight position**

We have summarized the values for a number of VW models from VW workshop manuals in one table below. The "left/right" column indicates how much difference there may be between the left and right front wheels. We have calculated the conversion from degrees/minutes to decimal degrees in the "decimal°" column (see also page 33). The maximum value and minimum value in decimal degrees are also calculated in the table.

For example, if you have a 1959 VW Beetle (Type 11) with King Pins, then the Camber Angle is 0.67°, the maximum measured Camber Angle may be 1.17° and the minimum allowed Camber angle is 0.17°. The far right column indicates whether the Camber Angle can be adjusted. We will discuss the adjustment of the Camber angle in edition 29.

left/right	decimal °	maximum °	minimum °	adjust
30'	0,67	1,17	0,17	fixed
30'	0,67	1,17	0,17	fixed
30'	0,67	1,17	0,17	fixed
30'	0,50	0,83	0,17	adjustable
30'	0,50	0,83	0,17	adjustable
30'	1,00	1,33	0,33	adjustable
ideal 0'	0,67	1,17	0,17	fixed
30'	0,67	1,17	0,17	fixed
30'	0,67	1,00	0,33	adjustable
20'	1,33	1,50	1,17	adjustable
30'	1,17	1,58	0,67	adjustable
30'	0,33	0,83	-0,17	adjustable

The Camber Angle of the front wheels is always a positive value in our VWs (positive Camber, see edition 25), this means that the front wheels are further apart at the top compared to the bottom.

Front axle

You can measure the Camber Angle with a digital level. This tool will give you an idea if the Angle is reasonably within the prescribed values. You can then have an exact measurement and adjustment done by a specialist.

Make sure the car is level (see preparations on page 29). Remove the wheel cap and, if necessary, the hub cap. Mark the underside of the rim with chalk or tape (photo 12). Place the digital level vertically against the rim. If the rim has some damage, or there are some paint drops, choose a place where the rim is in perfect condition. Our level has a magnetic bottom, which is very convenient. Since the level is too short for the 15-inch rims, we use a metal bar to place against the rim, to get a good measuring surface. We note for this T2b Bus an angle of 88.20°, or +1.80° Camber for the left wheel (Photo 12). Push the car forward so that the wheel spins a half turn, until the mark you made on the rim (in our case, a piece of

yellow tape) is at the top. Do the measurement again. We now also measure +1.80° (photo 13). Calculate the average of the two measurements, if different, this will give a useful value for the Camber angle of the left front wheel. For this VW Bus, it is +1.80°.

We consult the table with the Camber value for the VW Bus between 1967 and 1979 (model with ball joints), then we see that the minimum Camber Angle should be +0.33° and maximum +1.00° (we use the degrees expressed in decimals). The measurement of +1.70° Camber angle on the left wheel says that our VW Bus is 0.70° above the maximum value. Then do the same for the right front wheel.

The table also shows the maximum difference between left and right. For this VW Bus, that is 30', or 0.50° decimal. In the manuals, the Camber Angle is also measured with the front wheels turned 20°. If the measurements are outside the prescribed values, you will have to adjust the Camber Angle, if that is possible on your model (see table).

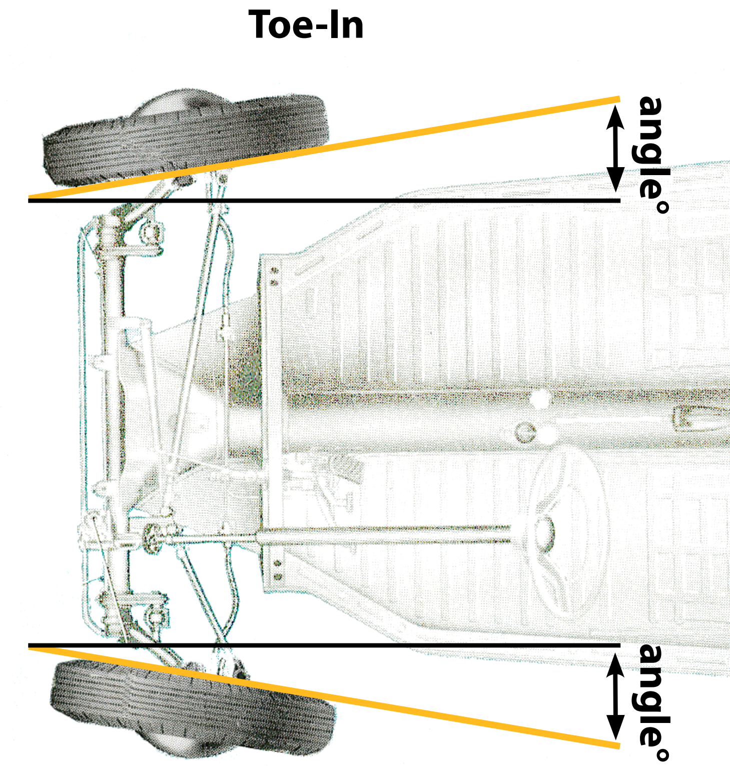
In edition 29 we show how to adjust the Camber Angle, a basic adjustment you can do yourself, a final and accurate adjustment is done at a specialist with precision tools. If an adjustment is not possible, you will have to check the front axle parts and possibly replace them.

Toe

A second important measurement is Toe. To measure Toe on the front wheels, the following conditions must be met:

- **chassis is level**
- **the wheels are on the ground**
- **car is completely empty**
- **front wheels in straight position**

We explained in edition 26 what Toe is (drawing on the right). In a **rear-wheel-drive car**, the front wheels are pushed out in front while driving, by setting the front wheels a little inward when



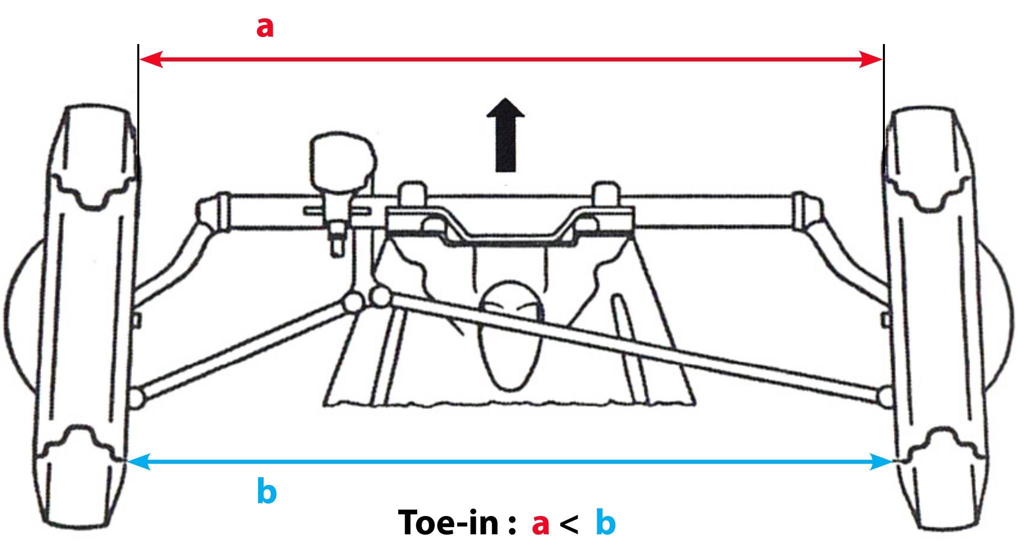
TOE FRONT WHEELS	YEARS	Front axle type	Toe (mm)	Deviation	adjust
Type 11, 14, 15	1952-1957	king pins	1 to 3mm		adjustable
	1958-1960	king pins	1 to 3mm		adjustable
	1961-1965	king pins	2 to 4 mm		adjustable
	1966-1969	ball joints	1,8 to 5,4 mm	+30' +/-15'	adjustable
	1970-1979	ball joints	1,8 to 5,4 mm	+30' +/-15'	adjustable
	VW1302/1303	MacPherson	1,8 to 5,4 mm	+30' +/-15'	adjustable
Type 2	1950-1962	king pins	0 mm +/-1mm		adjustable
	1963-1967	king pins	0 mm +/-1mm		adjustable
	1968-1979	ball joints	0 to 3,3mm		adjustable
Type 3	1967-1970	king pins	4 to 6mm	+40' +/-15'	adjustable
Type 4 (VW411/412)	1971-1974	MacPherson		+20'+/-15'	adjustable
VW Golf/Jetta/Scirocco	1974-1984	MacPherson	-0,5 to -3mm	-5' tot -30'	adjustable

the car stands still, this is Toe-in, the aim is to get the wheels as straight as possible while driving. The VW Golf is a **front-wheel-drive car**, and will do just the opposite. A setting with Toe-Out will be necessary with the VW Golf and derivatives, Toe-Out is a negative value.

In the table we have listed the Toe values for the front wheels. A positive Toe value on the front wheels means Toe-In (Toe-In is typical for rear-wheel drive) and a negative Toe value means Toe-Out (Toe-Out, typical for front-wheel drive).

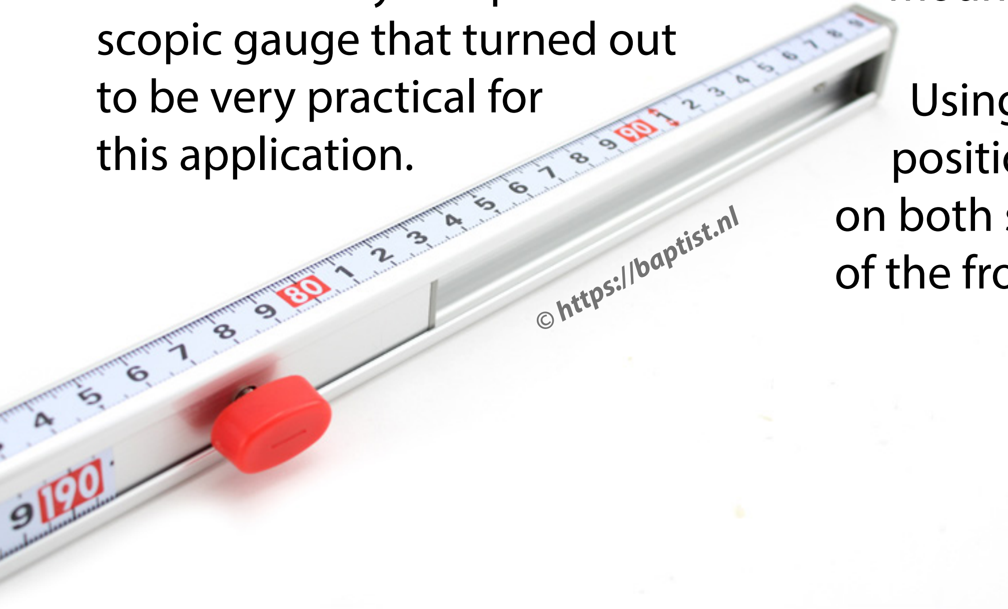
The Toe values are so small, say ten seconds (5'), which is 5 divided by 3600 or 0.001389°, that we cannot measure it with the digital level or protractor, that can only be done with precision tools. We will therefore use the prescribed values in millimeters, we can measure that ourselves. The values fluctuate around a few millimeters.

This drawing is from edition 26. This is the front axle in top view. When the distance between the wheels at the front (a) is less than the distance at the rear of the wheels (b), we have a Toe-In setup.



Front axle

To measure Toe, you can make your own tool, for example with a metal tube that is just not wide enough to place between the two rims, or two metal tubes that slide into each other. We found this very inexpensive telescopic gauge that turned out to be very practical for this application.

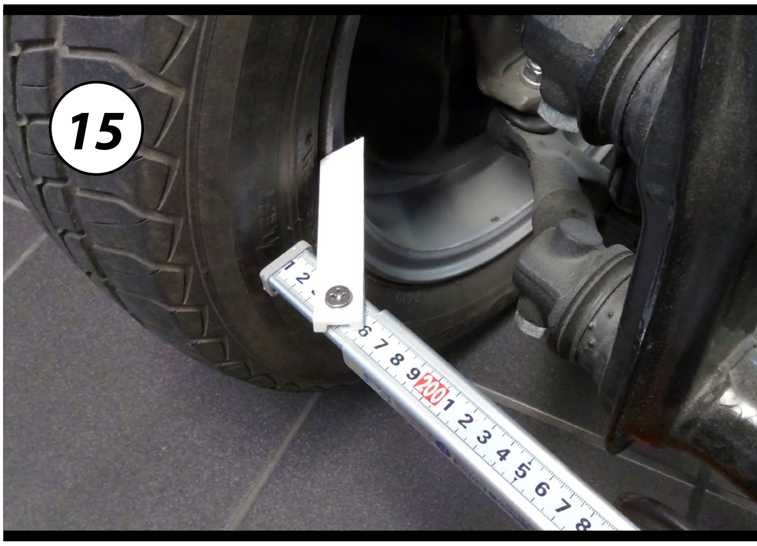


We show the setup in photo 14 on a VW Beetle chassis because it works easier to take photos of the setup. In practice, Toe is measured when the car is complete, with body and engine mounted (see preparations).

Using two axle stands, we position the telescopic gauge on both sides against the center of the front of the rims.

On most VW models, it will be difficult to place the measuring tool exactly in the center of the rim because the front axle is in the way. Measuring a little off-center is admittedly not that bad. If the front axle parts are too much in the way, you can make an extension tool as we show in photo 15.

To measure Toe-In at the front of a rear-wheel-drive car, the VW workshop manual recommends that before taking the measurement, pull the front wheels apart at the front (photo 16) to eliminate the (allowed) play of the King Pins or ball joints and steering rods to make the measurement more accurate.



#81 Front axle

Now measure the distance between the rims at the center of the rim on the front of the rim. Mark this point on the rim with a lick of paint or tape. Push the car forward until the marked point on the rim is turned 180°. To be sure, push the rims apart again at the front.

Now measure the distance between the rims at the rear. This distance should be greater than the first measurement against the front of the rims if you want to have Toe-In. The value should match the value in the table, plus or minus the allowable deviation.

Our Beetle with ball joints is from 1971 and, according to the table on page 42, is allowed to have Toe-In between 1.8 mm and 5.4 mm. If the Toe-In is not within the allowed value, you can make a temporary adjustment yourself, adjusting the Toe is explained in edition 29.

Values are also given by VW with force applied to the wheel, with a certain weight, we did not perform this measurement. Also, Toe is measured with rotated front wheels (angle of 20°), Toe must also meet certain values in this condition. For simplicity, we measured only the front wheels in the straight ahead position without additional load/weight.

For a front-wheel-drive car, for example the 1974 VW Golf, start with the distance of the wheels at the back of the rims, as this distance should be smaller than at the front. This type of car should have Toe-Out as you can see from the negative value in the table on page 42. In photo 17 we show a slide from the introductory course for the 1973 Volkswagen Golf.

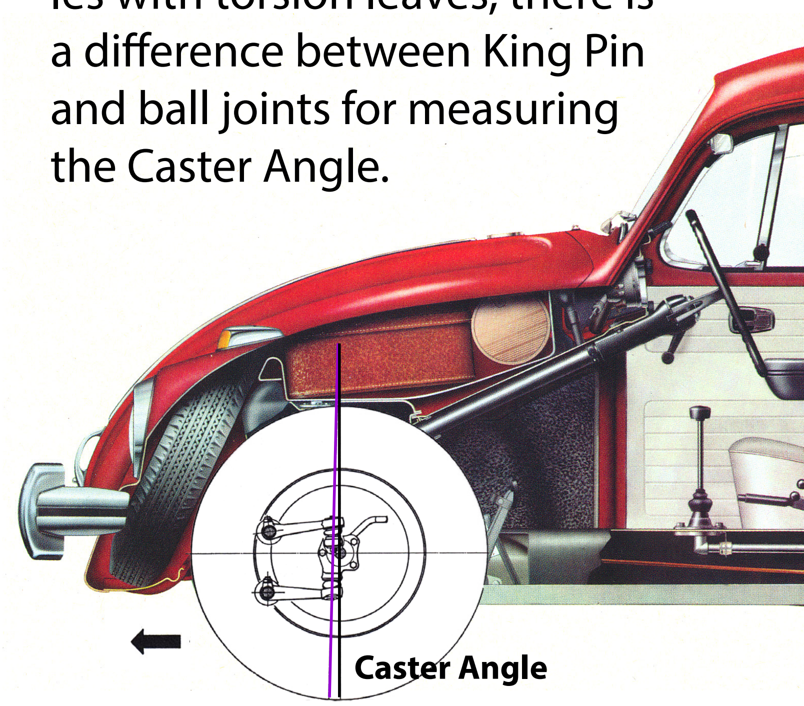
Caster Angle

Caster Angle is a setting that applies to the front wheels only.

To measure the Caster Angle of the front axle, the following conditions must be met:

- **chassis is level**
- **the wheels are on the ground**
- **car is completely empty**
- **front wheels in straight position**

Below we show the table with the values for the Caster Angle for our classic VWs. For front axles with torsion leaves, there is a difference between King Pin and ball joints for measuring the Caster Angle.

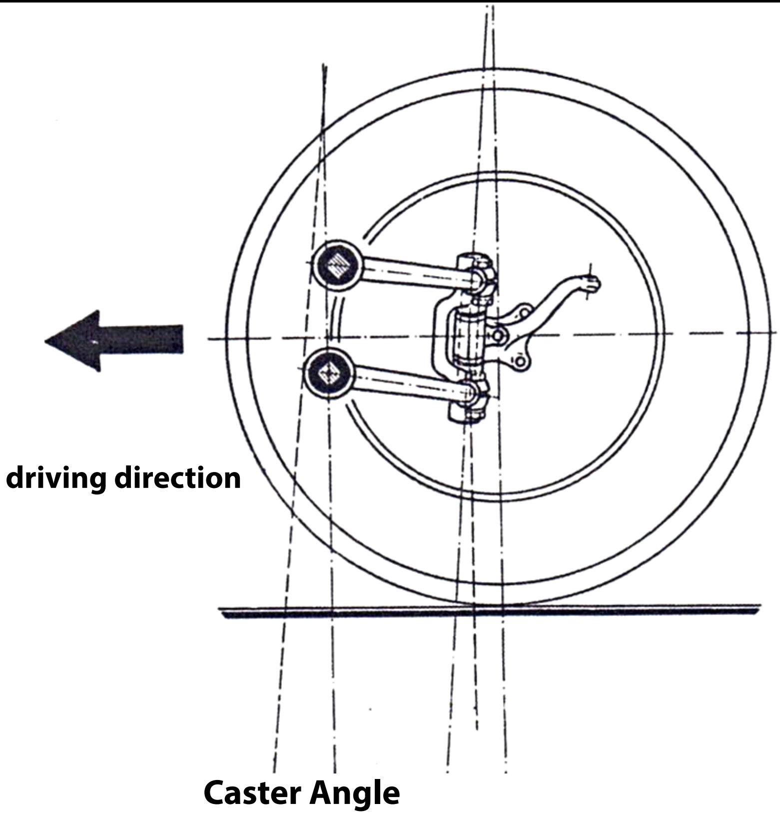


CASTER FRONT WHEELS	YEARS	Front axle type	Caster	Deviation	adjust
Type 11, 14, 15	1952-1957	king pins	2°30'	+/-30'	fixed
	1958-1960	king pins	2°30'	+/-15'	fixed
	1961-1965	king pins	2°	+/-15'	fixed
	1966-1969	ball joints	3°20'	1°	fixed
	1970-1979	ball joints	2°	+/-35'	fixed
	VW1302/1303	MacPherson	2°	+/-35'	fixed
Type 2	1950-1962	king pins	0°		fixed
	1963-1967	king pins	0°		fixed
	1968-1979	ball joints	3°	+/-40'	fixed
Type 3	1967-1970	axle tilt	11°50'		fixed
Type 4	1971-1974	MacPherson	1°45'	+/-35'	fixed
VW Golf/Jetta/Scirocco	1974-1984	MacPherson	1°50'	+/-30'	fixed

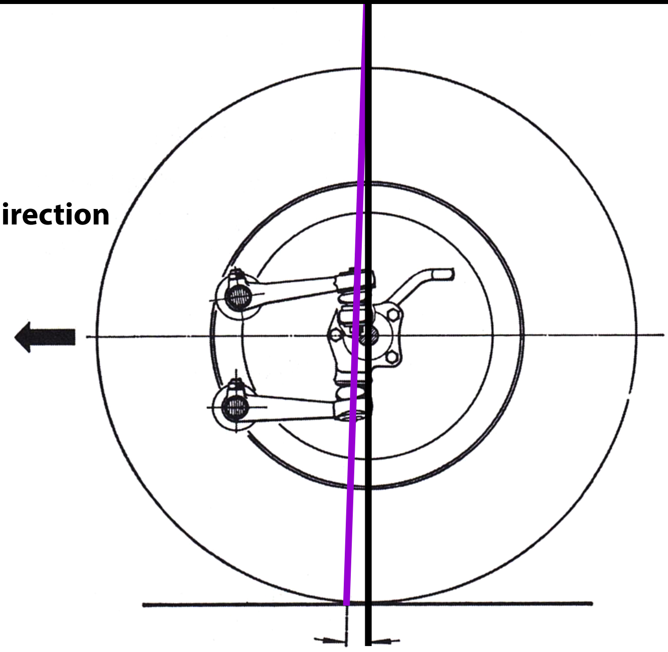
#81 Front axle

Front axle with King Pins

For a front axle with King Pins, the Caster Angle is given as the angle (tilt) of the front axle tubes (housing containing the torsion leafs). We show this on the drawing on the right. To measure it, place the digital level against the front axle tubes as shown in the picture below. Compare the value with the prescribed value.



We measure the Caster angle of our 1953 VW Beetle, it is 2° on the left side (see photo 18 below, we read 88° on the level, 90° minus 88° is 2°). We do the same on the right side, we measure 87.95°, or 2.05°. According to the table on the previous page, the Caster Angle should be 2°30' with a 30' margin. Our 1953 Beetle has a Caster Angle of 2°, just within the allowed value.



Front axle with ball joints
For ball joints, Caster Angle is given as the angle around which the wheel rotates. That is the combination of the front axle tubes tilt and the tilt of the steering knuckle itself (see drawing at right). This is a bit trickier to measure. We do it with the digital level, against the steering knuckles (photo 19). The drawing on the right should help a bit to understand exactly what to measure. We measure a Caster Angle of 82.30°, or 7.70° (see photo below), on our 1969 Karmann Ghia. Converted to degrees and minutes, this is 7° 42'. The table on page 47 says that for the Type 14 from 1966 to 1969, the Caster Angle may be 3° and 20', with an allowable margin of 1°. It concludes that on this Ghia the Caster is far too large. Note, the adjustment of the rear torsion bars affect the Caster Angle on the front wheels! So, work to be done on this car!

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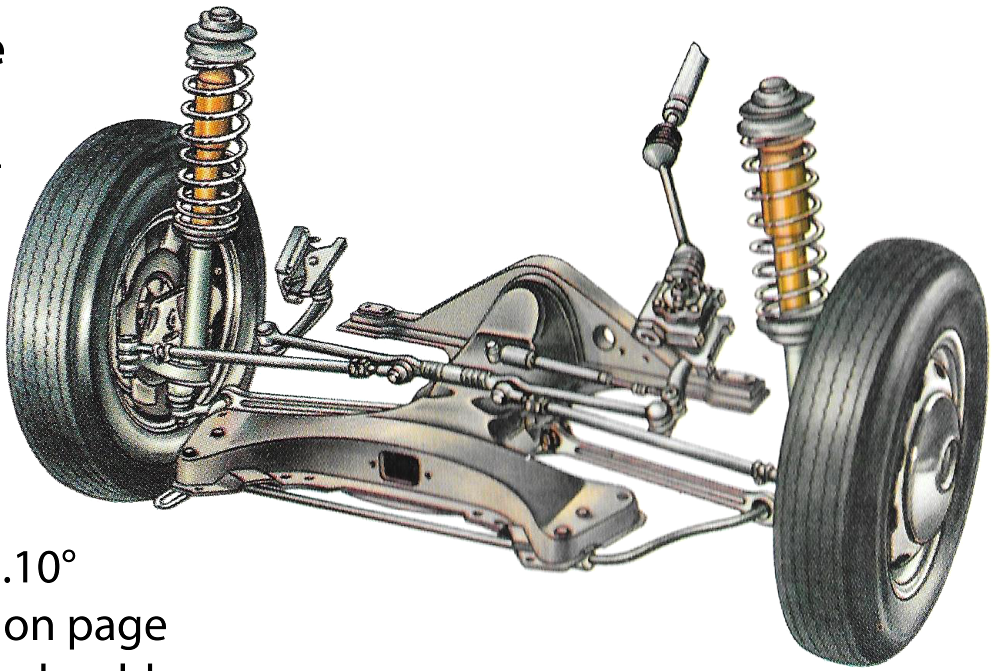
#81 Front axle

MacPherson front axle
The Caster Angle of the MacPherson strut is given as the angle of the strut. You can measure that by holding the level against the bottom of the strut.



We measure 87.90°, or 2.10° Caster Angle. The table on page 47 says the Caster Angle should be 2°, with a 35' margin. So the measured value (photo 20) is within the allowed value.

Remember to do the conversion between degrees minutes and decimal degrees if necessary (see page 33).

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Conclusion

Caster Angle cannot be adjusted on any classic VW. It is determined by the parts themselves and their assembly. If the measurement is very different from the value in the table, they are probably deformed or damaged and replacement is the only solution, unfortunately.
Of course, we would all love to have the professional devices that Volkswagen showed in its courses (photo 21), but they were very expensive and reserved for the official VW resellers unfortunately. Below we show a photo from the Volkswagen course of the early 1970s.

This series of articles on wheel geometry aims to make the enthusiast aware about the importance of adjusting the chassis correctly during a restoration but also to check the values after purchase. In the next edition we will discuss the rear axle, and in edition 29 we will explain how the adjustment is done on both the front and rear axles.

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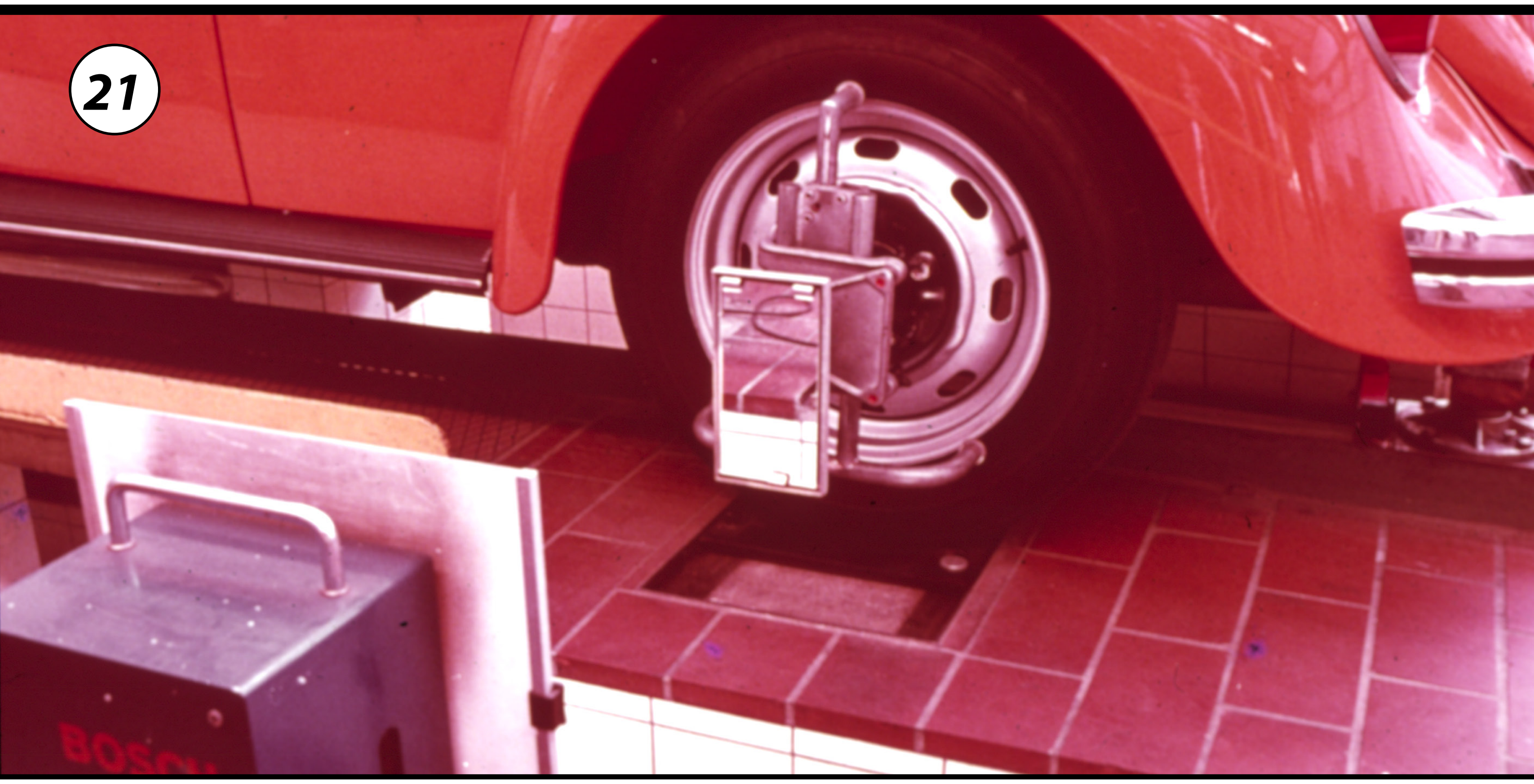

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