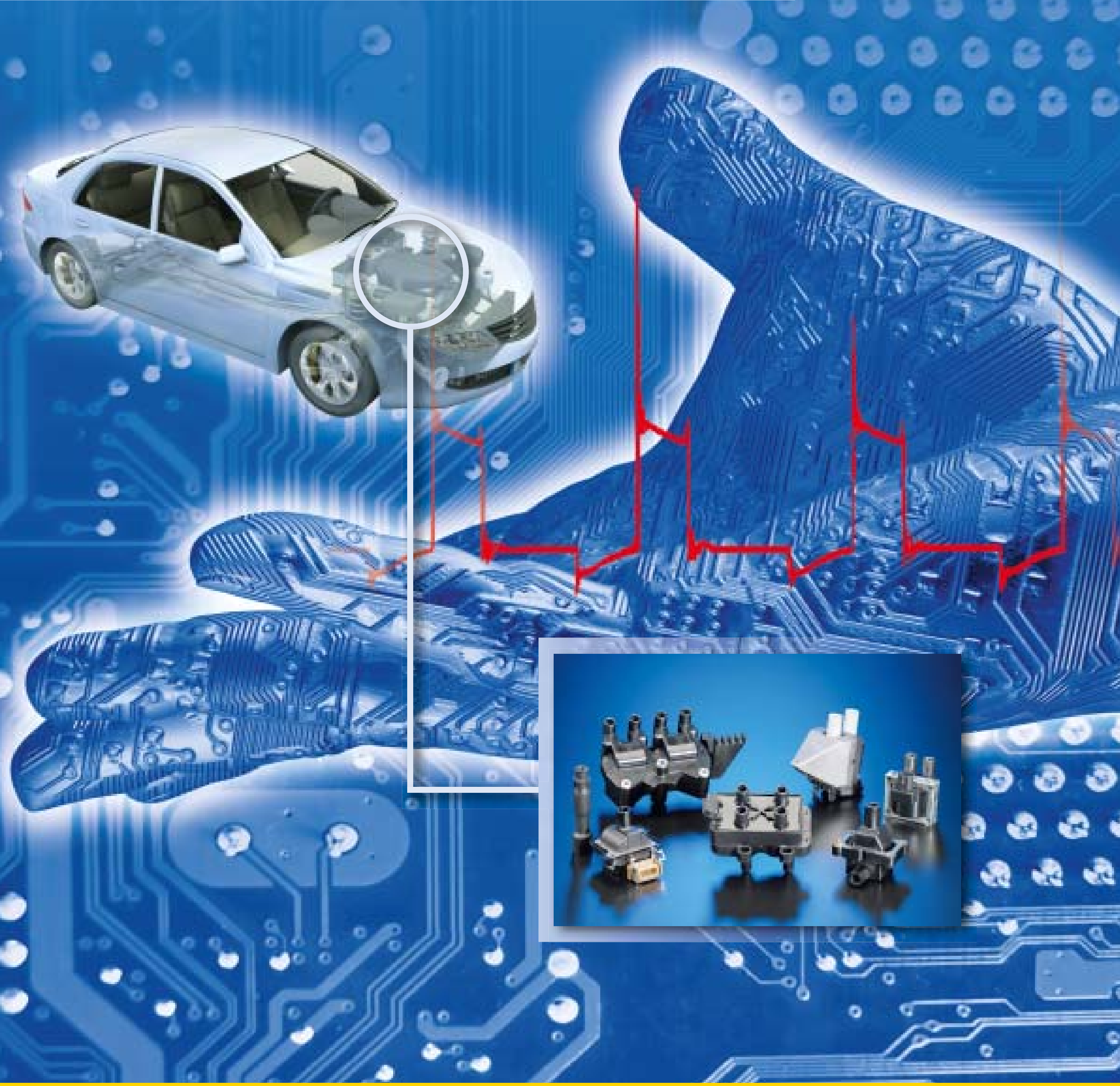
Ignition coils in motor vehicles

Function, diagnosis, troubleshooting.



Ideas today for the cars of tomorrow

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Source: Illustrations (Fig. 1-6 edited) taken from Fachkunde Kraftfahrzeugtechnik, 28th edition 2004, published by Europa-Lehrmittel.

Ignition coil structure

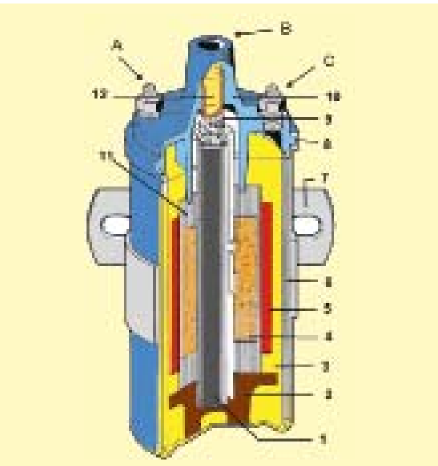


Fig. 1: Ignition coil structure

1. Iron core
2. Insulating mass
3. Casting compound
4. Secondary winding
5. Primary winding
6. Metal sheath
7. Mounting clip
8. Housing
9. High-voltage spring contact
10. Insulating cover
11. Insulation material
12. High-voltage output

A. Terminal 15
B. Terminal 4
B. Terminal 1

The design of a conventional ignition coil is basically similar to that of a transformer. The ignition coil‘s task is to induce a high voltage from a low voltage.
Alongside the iron core, the main components are the primary winding, the secondary winding and the electrical connections.

The laminated iron core has the task of reinforcing the magnetic field. A thin secondary winding is placed around this iron core. This is made of insulated copper wire about 0.05-0.1 mm thick, wound around up to 50,000 times. The primary winding is made of coated copper wire about 0.6-0.9 mm thick and is wound over the secondary winding. The Ohmic resistance of the coil is about 0.2-3.0 Ohm primary and 5-20 kOhm secondary. The winding ratio of primary to secondary winding is 1:100. The technical structure can vary, depending on the ignition coil‘s area of application.

In the case of a conventional cylinder ignition coil, the electrical connections are designated as terminal 15 (voltage supply), terminal 1 (timer) and terminal 4 (high-voltage connection). The primary winding is connected with the secondary winding to terminal 1 via a common winding connection. This joint connection is termed „economising circuit“ and is used to simplify coil production.

The primary current flowing through the primary winding is switched on or off via the timer. The amount of current flowing is determined by the coil‘s resistance and the voltage applied at terminal 15. The very fast current direction caused by the timer changes the magnetic field in the coil and induces a voltage impulse that is transformed by the secondary winding into a high-voltage impulse. This passes through the ignition cable to the spark plug‘s spark gap and ignites the fuel-air mixture in a spark-ignition engine.

The amount of high voltage induced depends on the speed of change in the magnetic field, the number of windings on the secondary coil and the strength of the magnetic field. The opening induction voltage of the primary winding is between 300 and 400 V. The high voltage on the secondary coil can be up to 40 kV depending on the ignition coil.

Ignition coils for ignition systems with rotating high-voltage distribution

These cylinder ignition coils are used in vehicles with ignition distributor in contact-controlled or transistor-controlled ignition systems. The three-pole electrical connection corresponds to that of a conventional ignition coil.

The primary circuit receives its voltage supply through terminal 15. The timer is connected to terminal 1 of the ignition coil and supplies the primary winding with ground. The high-voltage wire of the timer is connected to terminal 4. Whereas conventional ignition coils are still being used with older vehicles, ignition coils with integrated electronic control units are used today with vehicles equipped with transistor ignition.

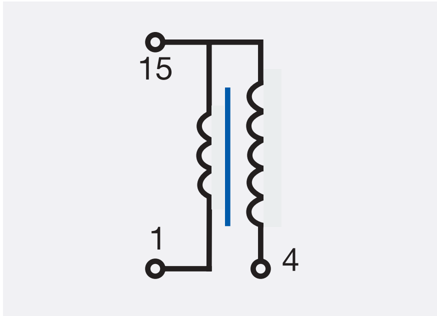


Fig: Ignition coil

Twin-spark ignition coils

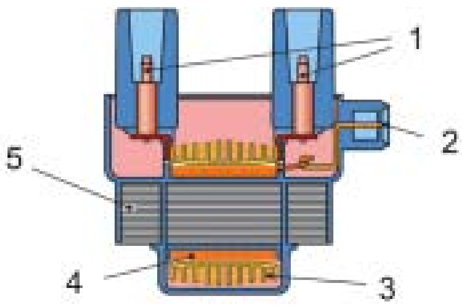


Fig. 2: Twin-spark coil

1. High-voltage connections
2. Low-voltage connection
3. Secondary winding
4. Primary winding
5. Iron core

Twin-spark coils are installed in ignition systems with static high-voltage distribution. These ignition coils are used with engines with an even number of cylinders.

The primary winding and secondary winding of the twin-spark coil each have two connections.

The primary winding is connected at terminal 15 with voltage supply (plus) and at terminal 1 (ground) with the output stage of the ignition timer or control unit. The secondary winding is connected to the spark plugs with the outputs (4 and 4a). With these systems, two spark plugs each are supplied with high voltage from one ignition coil. Since the ignition coil generates two sparks simultaneously, one spark plug has to be in the working cycle of the cylinder and the other offset by 360° in the ejection cycle.

In a four-cylinder engine, for example, cylinders 1 and 4 are connected to one ignition coil, and cylinders 2 and 3 to another. The ignition coils are triggered by the ignition output stages in the control unit. This receives the TDC signal from the crankshaft sensor in order to begin triggering the right ignition coil.

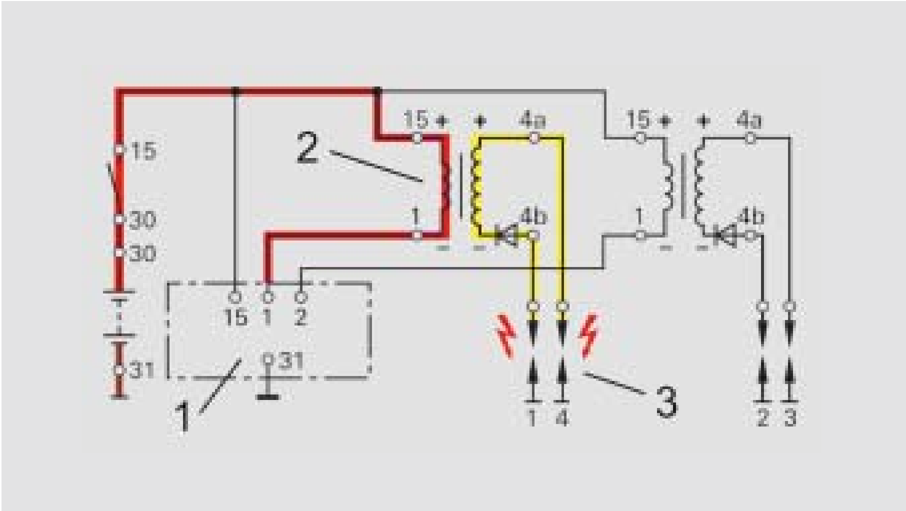


Fig. 3: Ignition system with twin-spark coil

1. Ignition control unit
2. Ignition coil
3. Spark plugs

Four-spark ignition coils

Four-spark ignition coils replace two double-spark coils in four-cylinder engines. These coils each have two primary windings, each of which is triggered by a control unit output stage. Secondary winding is only available once. At its outputs, there are two connections for the spark plugs which are switched alternatively through diode cascades.

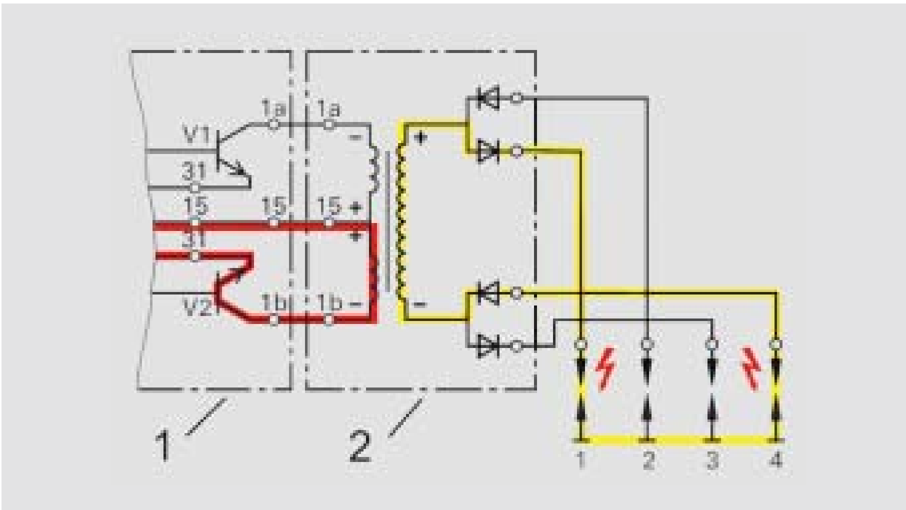


Fig. 4: Ignition system with four-spark ignition coil

1. Ignition control unit
2. Ignition coil

Single-spark ignition coils

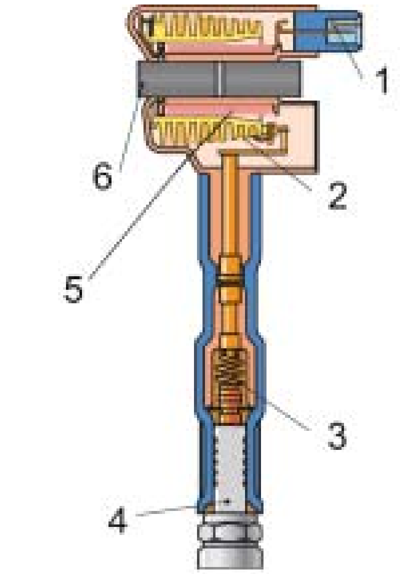


Fig. 5: Single-spark coil

1. Low-voltage connection
2. Secondary winding
3. High-voltage connection
4. Spark plug
5. Primary winding
6. Iron core

With systems with single-spark ignition coils, one ignition coil with primary and secondary winding is assigned to each cylinder. These ignition coils are usually installed directly at the cylinder head above the spark plug.

These coils are also connected with the primary winding at terminal 15 (voltage supply plus) and at terminal 1 (ground) with the control unit. The secondary winding is connected with the output of terminal 4 to the spark plug. If a terminal 4b should be present, this connection is used to monitor misfiring. Triggering is in the sequence specified by the control unit.

A single-spark coil‘s circuit corresponds to that of a conventional ignition coil. In addition, a high-voltage diode is used in the secondary circuit to suppress the so-called closing spark. The undesired spark produced when the primary winding is switched on through self-induction in the secondary winding is suppressed by this diode. This is possible since the secondary voltage of the closing spark has opposite polarity to the ignition spark. The diode blocks in this direction.

With single-spark coils the second output of the secondary winding is routed to ground through terminal 4b. A measuring resistor is installed in the ground cable to monitor ignition, this represents the drop in voltage caused by the ignition current during sparkover as a measured parameter for the control unit.

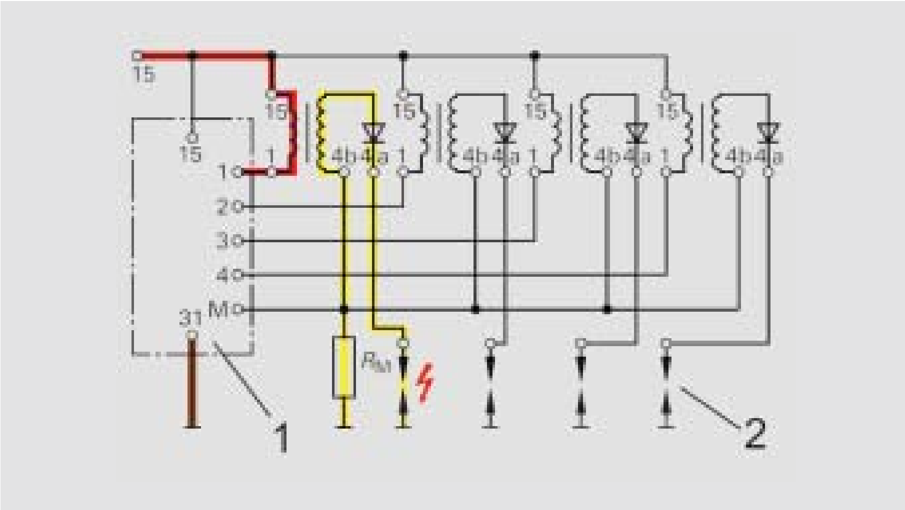


Fig. 6: Ignition system with single-spark coils

1. Ignition control unit
2. Spark plugs

Possible reasons for failure

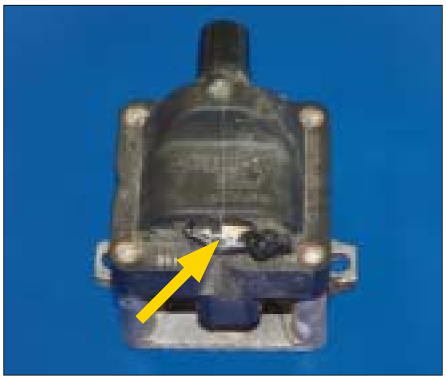


Fig.: Short-circuit

Internal short-circuits
Overheating of the coil caused by the ageing process, a faulty ignition module or a faulty output stage in the control unit.

Fault in the control voltage
The coil charging time increases on account of the voltage supply being too low, this can lead to premature wear or excess load on the ignition control unit or the output stages in the control unit.
This can be caused by a faulty cable or weak battery.

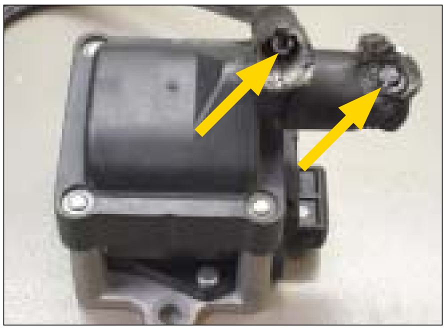


Fig.: Contact fault

Mechanical damage
Damage to the ignition cables through marten bites.
A faulty valve cover seal and escaping motor oil can damage the insulation of plug slot coils.
Both causes lead to sparkover and thus to premature wear.

Contact fault
Contact resistance in the wiring due to humidity penetrating in the primary and secondary area, also frequently caused by engine washing or the use of grit in winter.

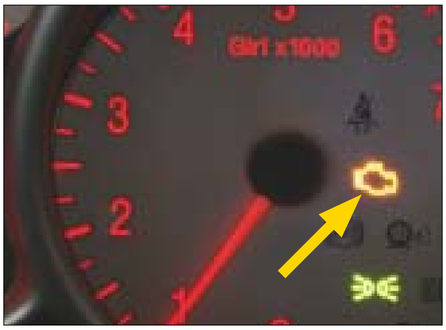


Fig.: Failure

Faults can become noticeable as follows:
- Engine does not start
- Vehicle misfires
- Poor acceleration or loss of power
- Engine control unit switches to safe-home mode
- Engine warning lamp lights up
- Fault code is stored

Diagnosis

Dismounted state

There are different possibilities available for checking the ignition coil: testing the resistance values of the coils using the Ohmmeter.

Depending on the ignition system and ignition coil design, the following reference values apply: (heed manufacturer's instructions)

Cylinder ignition coil (transistor ignition system)
Primary: 0.5 Ω – 2.0 Ω
Secondary: 8.0 kΩ – 19.0 kΩ

Dismounted state

Cylinder ignition coil (electronic ignition system with map-controlled ignition)
Primary: 0.5 Ω – 2.0 Ω
Secondary: 8.0 kΩ – 19.0 kΩ

Single-spark or twin-spark coil (fully electronic ignition system)
Primary: 0.3 Ω–1.0 Ω
Secondary: 8.0 kΩ – 15.0 kΩ

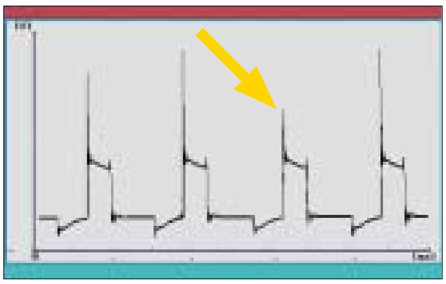
Practical tip

Note:
Should a high-voltage diode be built into an ignition coil to suppress sparks, resistance measurement at the secondary coil is not possible.

In this case, the following method is helpful:
Connect a voltmeter in series between the secondary winding of the ignition coil and a battery. If the battery is connected in the diode‘s conducting direction, the voltmeter must display a voltage. After reversing the polarity of the connections in the blocking direction of the diode, no voltage may be displayed. If no voltage is indicated in either direction, an interruption in the secondary circuit must be assumed. If a voltage is indicated in both directions, the high-voltage diode is faulty.

Installed state

The following tests can be used:
- Test the ignition coil for mechanical damage.
- Check the housing for hairline cracks or casting compound escaping.
- Check electrical wiring and plug-type connections for damage or oxidation.
- Check voltage supply to the ignition coil.
- Read out the fault store using a diagnosis unit.
- Engine control with ignition monitoring.
- Representation of the high-voltage curve using an oscilloscope or ignition oscilloscope.



During all testing work on the system, it must not be forgotten that faults that are established during tests with the oscilloscope are not necessarily faults caused by the electronic system, they can also be caused by a mechanical problem in the engine. This can be the case, for example, if compression is too low with one cylinder, which means the oscilloscope shows the ignition voltage on this cylinder to be lower than that on the other cylinders.

Note:
Although diagnosable engine management systems are installed in today‘s vehicles, the use of a multimeter or oscilloscope is necessary when checking ignition systems. In order to interpret the measuring results or images shown correctly, additional employee training is usually required. One important pre-requisite for successful diagnosis is a careful visual inspection at the beginning of the troubleshooting process.

Practical example for fault diagnosis in day-to-day garage work

We would like to demonstrate the diagnosis of a twin-spark coil using the following example „combustion miss“. Vehicle: Alfa Romeo 147 1.6 TS with twin-spark ignition. Each cylinder has a main plug and a secondary plug. The ignition coils are triggered by the ignition output stages integrated in the engine control unit.

Diagnosis condition

Engine mechanics, battery, starting system and fuel system OK.

Customer complaint

- The customer reports a functional problem with the engine control system
- Warning information on the instrument cluster
  Fault: Engine monitoring system

Practical tip

Before you start diagnosis you should heed the following:
- To be able to assign the vehicle correctly, it is important that the vehicle documents (registration documents) are included with the job sheet.
- Check the battery voltage. A poor voltage supply can lead to system failure, faulty measurements or drops in voltage.

Check the system-related fuses. A quick look in the fuse box might eliminate the first possible fault source.

Troubleshooting

1. Using the diagnosis unit
Connect the diagnosis unit to the 16-pole OBD plug. Depending on the vehicle manufacturer and date of registration, a different diagnosis socket and additional adapter may have to be used.

Carry out the following applications at the diagnosis unit:

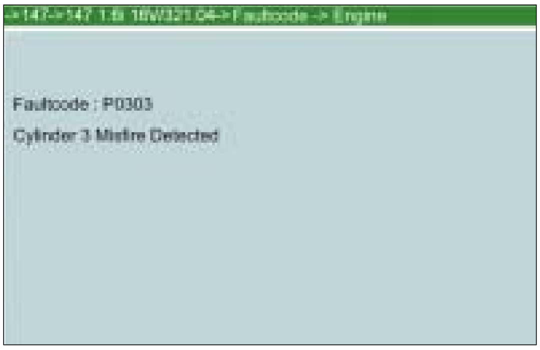
- Select program
- Select vehicle
- Select type of fuel
- Select model
- Select vehicle type

- Select required function
- Select system

Depending which diagnosis unit is used, additional safety instructions can be displayed here.

- Start fault diagnosis

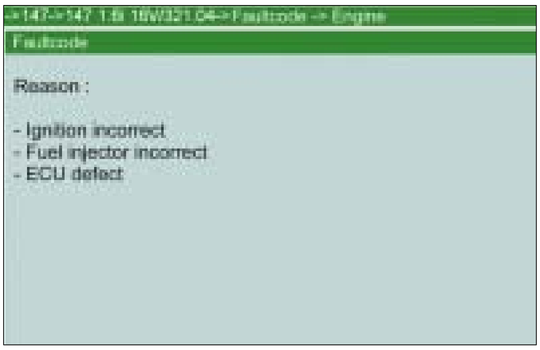
To build up communication with the control unit, sufficient battery voltage is required as well as the correct connection plug. Insufficient voltage supply to the control unit could be an indication of a wiring fault or a fault in the vehicle battery.



2. Read out the fault store

In this case, fault PO303 was stored.

- Combustion cylinder 3
- Combustion miss detected on cylinder 3



3. Evaluate the details

Here, additional information about a possible reason for the fault is stored

- Ignition faulty
- Injection valve faulty
- Control unit faulty

Note:

If several fault codes are displayed, delete the fault first. Then carry out a test drive with the diagnosis unit connected. Observe the parameters and read out the fault store.

4. Determining the reason for the fault

Preparations for engine diagnosis

- Prepare any additional diagnosis units that may be necessary such as multimeter or oscilloscope
- Look for the technical documents

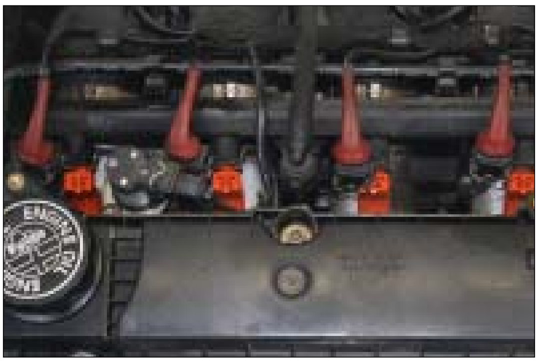
Remove the engine cover (if necessary)

5. Carry out a visual inspection

Before you start with the actual diagnosis, you should check the engine harness and plug-type connectors for damage, as far as they can be seen. Bends in cables, lack of strain relief or a so-called „marten bite“ on the harness could be a possible reason for failure.

6. Check voltage supply on the cylinder 3 ignition coil

- Remove the connection plug from the ignition coil
- Measure the voltage at the two-pole plug on the harness side
- Connect the red cable from the multimeter to PIN 2 (+), the black cable to engine ground (-). Switch the ignition on. A voltage of more than 10.5 Volts should be measured. Measured value shown: 11.84 V. Measurement OK.



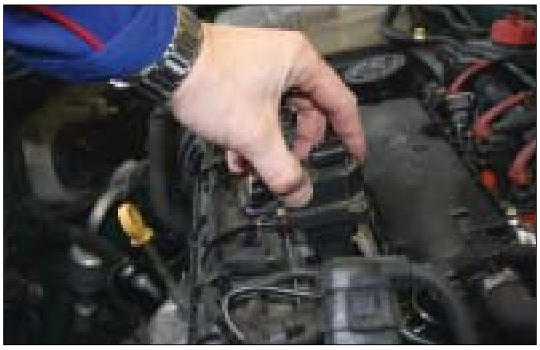
Practical tip

To check the voltage supply under load, we recommend repeating the measurement while actuating the starter. In order to prevent unnecessary fuel injection you must remove all the injection valve connectors first.

7. Check primary triggering of cylinder 3 ignition coil

- Remove the plug from the ignition coil
- Connect the oscilloscope. Connect the probe tips to PIN 1 and PIN 2 using the two-pole connection plug
- Remove the plug connections at the injection valves
- Start the engine

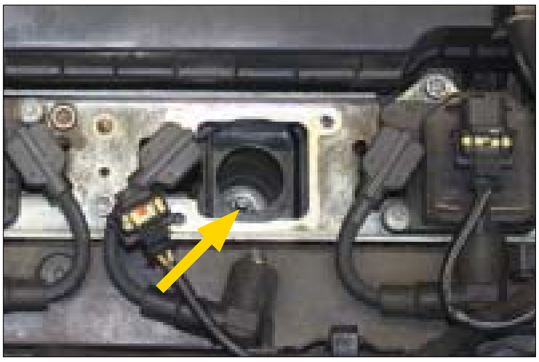
A signal should be clearly recognisable on the oscilloscope. In this example the measurement is successful.



8. Remove the ignition coil for further testing

- Remove the plug from the ignition coil
- Remove the high-voltage cable for the second spark plug
- Remove the fastening screws
- Pull the ignition coil off vertically and parallel to the plug slot

To avoid damage to the spark-plug connector, do not turn the ignition coil in any way.



Practical tip

Check plug slot for soiling caused by oil and water penetration. Remove and check the spark plugs.

9. Carrying out resistance measurement
Use the multimeter to check the removed ignition coil. Connect an ohmmeter directly to the component plug PIN 1 and PIN 2 to measure the primary winding.

- Reference value: 0.3 Ω - 1.0 Ω
- Actual value: 0.5 Ω (OK)

To measure the secondary coil, measure the test probes directly at the high-voltage outputs of the ignition coil.

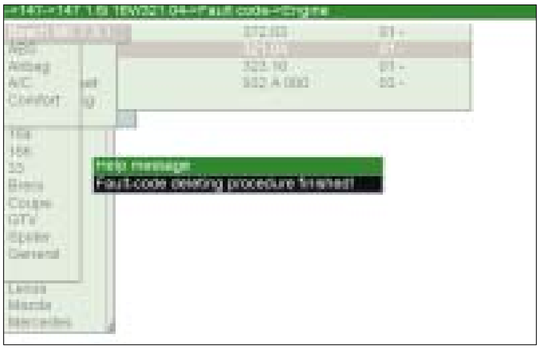
- Reference value: 8.0 kΩ –15.0 kΩ
- Actual value: ∞ (interruption secondary coil)

Always consult the manufacturer's specifications in this context.

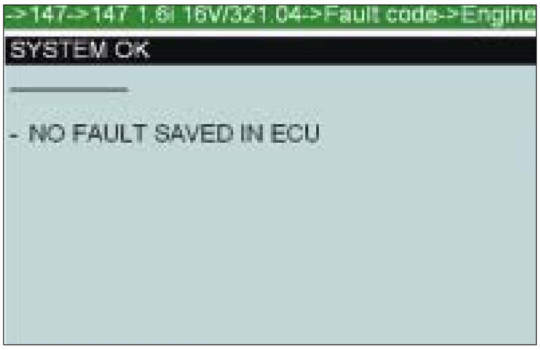
Practical tip

The ignition coils in this vehicle are identical and can be swapped for testing.

10. Replacing the ignition coil
Here, care must be taken that the spark-plug connector and the high-voltage cable for the second plug fit properly. Attach the ignition coil with the fastening screws. Then insert all the plug-type connections of the ignition coil and the injection valve plugs.



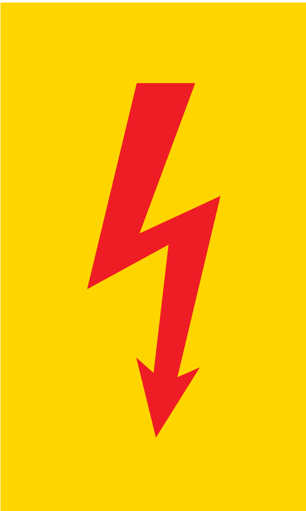
11. Deleting the fault store
During the diagnosis work, additional faults are detected by the control unit and have to be deleted before the test drive.



12. Carrying out a functional check
Carry out a test drive with the diagnosis unit connected. Then read out the fault store again.

Note:
Please always try to take the manufacturer‘s specifications into account during all testing and diagnosis work. Depending on the manufacturer, additional vehicle-specific testing methods may have to be taken into consideration.

Safety instructions



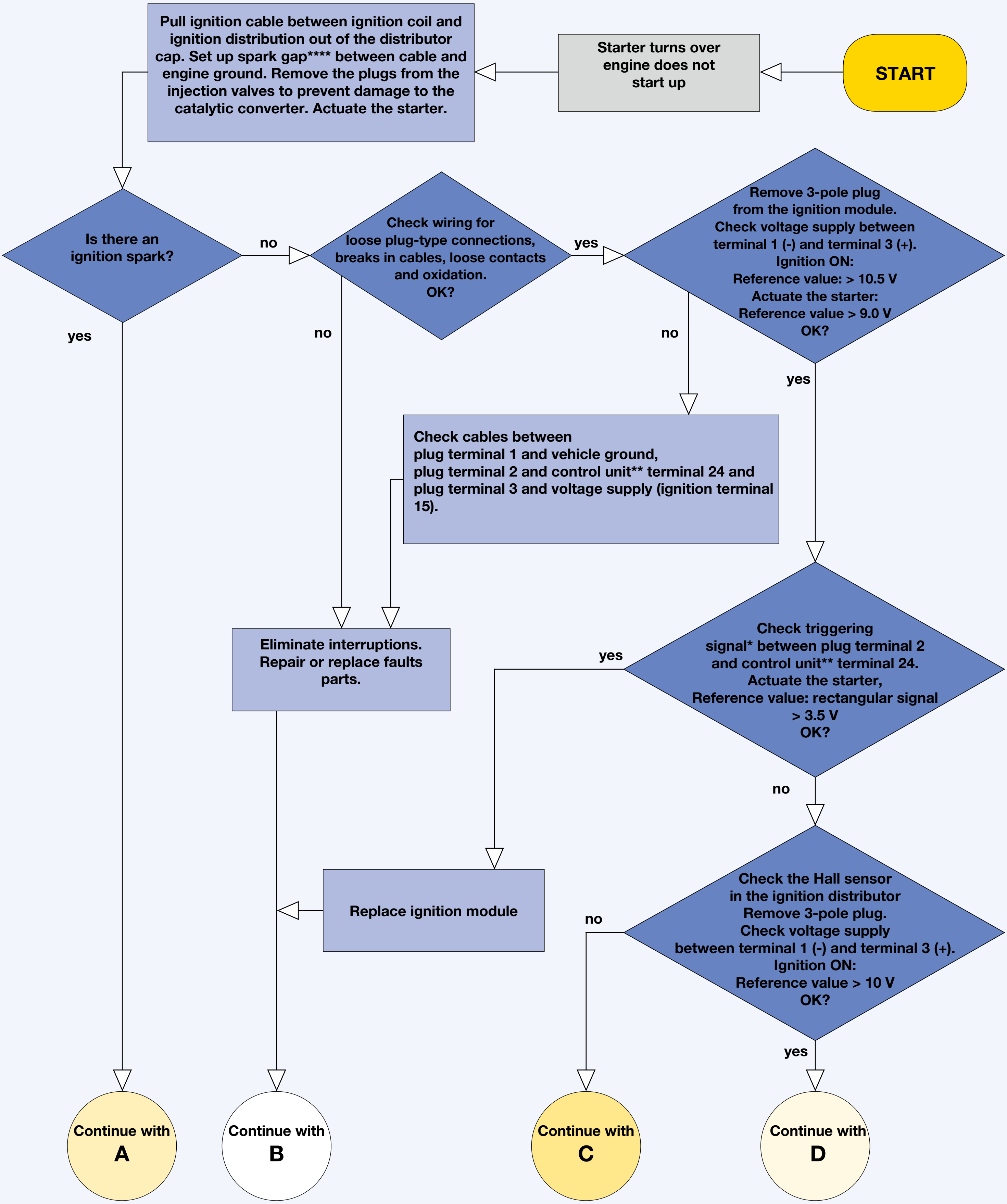
During work on electronic ignition systems, contact with live components can result in potentially fatal injuries.
This is not only valid for the high-voltage live secondary circuit, but also for the primary circuit. For this reason, testing and repair work should only be carried out by trained specialist staff.

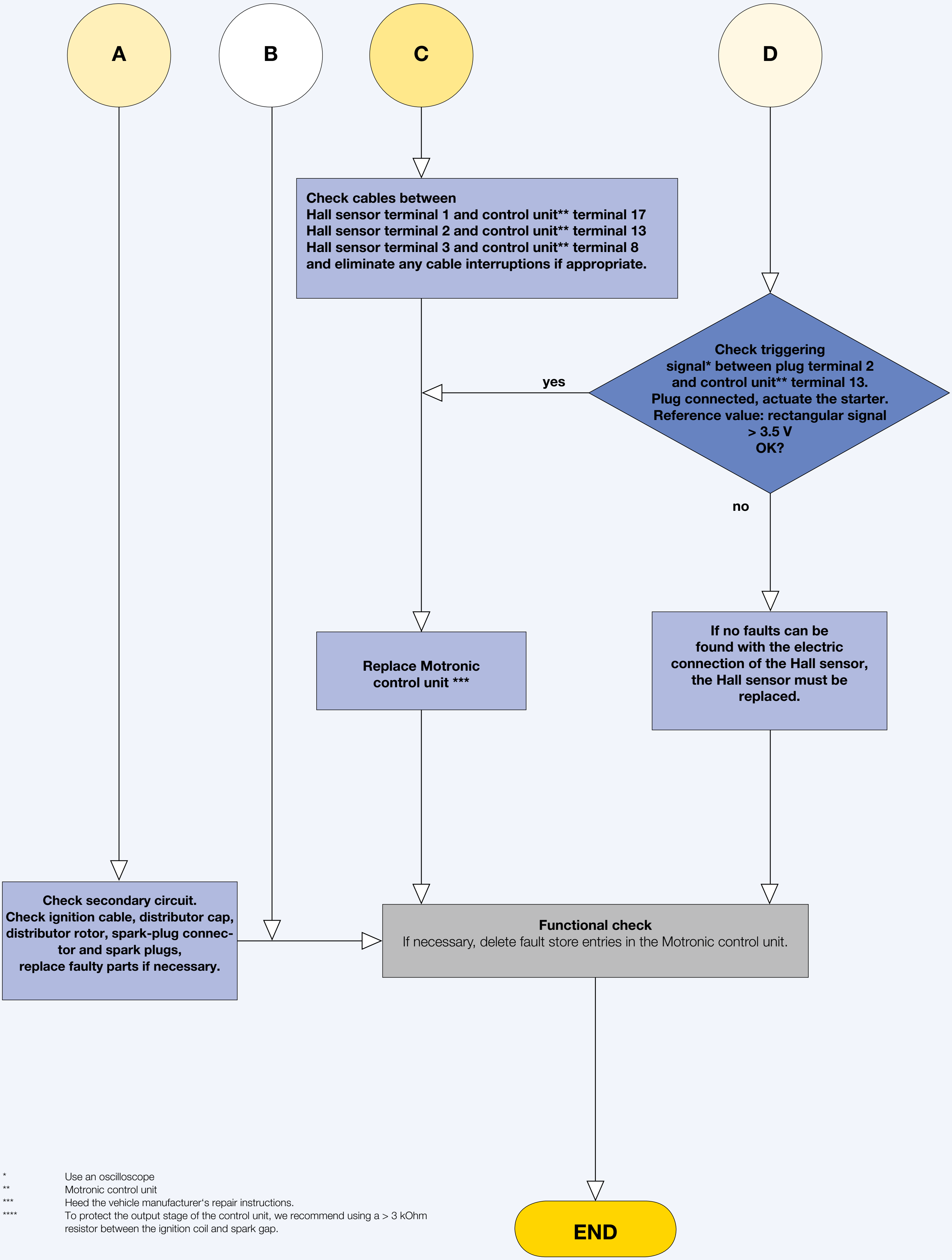
Please heed the following safety measures:

- Do not touch or remove the ignition cable, distributor cap and spark-plug connector with the engine running.
- Only connect or disconnect control units, plug-type connections and connection cables with the ignition switched off.
- Only carry out engine washing with the engine at a standstill and the ignition switched off.
- During all tests on the ignition system which require the engine to turn over at starter speed, the voltage supply to the injection valves should be interrupted in order to protect the catalytic converter.

Fault tree for ignition coil with integrated ignition control unit (ignition module)

Example: VW/engine code APQ, Motronic MP 9.0.
Diagnosis pre-requisite: Engine mechanics, battery, starting system and fuel system OK.





* Use an oscilloscope

** Motronic control unit

*** Heed the vehicle manufacturer's repair instructions.

**** To protect the output stage of the control unit, we recommend using a > 3 kOhm resistor between the ignition coil and spark gap.

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