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Diagnostics

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INTRODUCTION

Until relatively few years ago, the experience of mechanical technicians provided with a few basic tools was generally sufficient for a vehicle repair. However, the constant technical evolution of cars and the incorporation of new systems and components has increased the complexity of fault diagnosis, a task that can be erratic or ineffective without sufficient knowledge and the necessary resources.

A correct and orderly diagnostic protocol increases the chances of finding the source of the anomaly in the vehicle, as well as identifying the damaged parts of the system, to then carry out the repair or replacement in an efficient and successful way.

The logical guideline model or sequence to follow during the diagnostic process is essential for locating the fault and determining its possible solution while optimising both the resources available and repair times.

Following steps in an orderly manner will not be of much use if the technician lacks the necessary knowledge to carry out their work. The training of the repair professional and knowledge of the different vehicle systems and their components, both electrical and mechanical, is vitally important both when carrying out the diagnosis and the repair. The availability of tools and instruments is as necessary as the knowledge of the correct techniques for handling the various devices such as: OBD diagnostic tools, steering aligners, AC charging stations, wheel balancers, electronic testers, battery testers, oscilloscopes, beamsetters, etc.

Don't forget that the diagnosis of a vehicle begins when it arrives in the workshop, with the asking of concise questions that can be understood by the customer. It is likely that the receptionist will have to convey the information received to the person responsible for the repair, and it is important that no information is lost in the process. After an accurate diagnosis and the efficient repair of the vehicle, the technician will be able to determine, in many cases, the customer's satisfaction when the vehicle is handed back.

DIAGNOSTIC PRINCIPLES

The term diagnosis derives from the Greek word "διάγνωση", made up of: "dia" (through) + "gnosis" (knowledge), and indicates the capability to discern, distinguish or recognise, based on good judgement. Diagnostics in the automotive sector refers to the set of techniques and processes that can be applied to ascertain the origin of a fault or the cause of a malfunction. This determination is carried out based on the data, which is the systematically collected and ordered facts that make it possible to better judge what is happening in the vehicle based on the symptoms, to then go on to resolve the issue.

Generally, the fault solution requires the repair or replacement of the affected component. Sometimes, depending on the nature of the problem, these interventions include certain adjustments or can be resolved by updating the software of an electronic unit. In any event, the repair will not be concluded until the technician carries out the necessary tests to verify the correct functioning of the system and the satisfactory result of the intervention.

In order to be able to make a fast and effective diagnosis of the various vehicles that visit the workshop, the following are needed:

- Adequate technical training
- Manufacturer's information and data
- Tools, instruments and specific equipment
- Reasoning capacity

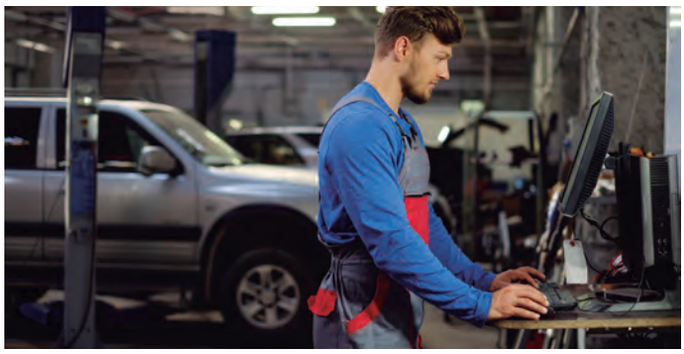
Adequate technical training

Generally, the repair technician undergoes two types of training: vocational and continuous. The vocational or initial training enables the person to enter the working world. It is carried out in a scheduled, continuous theoretical/practical format and usually ends with a work placement in a company for introduction into the labour market. In many cases, this training ends with the obtaining of a training qualification which is considered an essential requirement for the legal opening of a workshop.

Continuous training, on the other hand, is an unscheduled process of updating and recycling knowledge that is established in accordance with the evolution of the market and is carried out intermittently throughout the person's working life. It is designed so that the technician is always being trained in the competencies of their professional sector. There are tasks within the job function that can only be carried out if the required legal certification is held, such as, for example, the handling of fluorinated gases or the installation of gas injection systems in vehicles that do not have it, among others.

Manufacturer's information

It is important to have access to the technical information of the manufacturer or equivalent as, in many cases, it is essential for conducting tests and carrying out the repair. With it, the technician can consult, for example, the vehicle's electrical diagrams, the disassembly and assembly processes, tightening torques, tolerances, adjustments or settings, among other recommendations and safety warnings of the brand.



Necessary tools, instruments and equipment

The importance of having and knowing how to correctly operate the various work tools, as well as measuring equipment, electronic diagnostic tools and special tools among others, directly influences the quality of the testing of the affected system. The knowledge and appropriate use of this equipment means the problem can be located more quickly and accurately, thus optimising the time invested in the repair.

Reasoning capacity

This is an ability that enables people to solve problems, draw conclusions and consciously learn from the facts, in order to establish the necessary causal and logical connections between them. It is a skill that is developed over time by applying the diagnostic techniques and the knowledge obtained through training and accumulated experience.

All these factors contribute to the technician being able to perform their work dynamically, with ease and fluency.

RESOURCE OPTIMISATION

Using the available resources in the best way possible for the performance of the work activity contributes to the profit of the workshop and improvement of the service. Optimisation can be achieved by improving an activity, a method, a process or a system, etc. Nevertheless, financial and personnel savings are also a factor to take into consideration in the optimisation of resources.

To achieve the desired results, the workshop's objectives must be clearly defined so the resources available can be effectively managed, and these objectives can be reached in the most profitable way possible. It is advisable to set deadlines to achieve these objectives, as it helps to assess if the amount of allocated resources is sufficient and necessary. Equally, keeping the work areas and equipment clean and tidy helps when carrying out the daily workshop tasks, such as vehicle diagnostics.

One of the most important aspects in the optimisation of the workshop is the availability of sufficient tools and machinery for its personnel, as well as ensuring its correct operation and use.

Equipment in an electromechanical workshop

Depending on the characteristics, size and possible specialisation of the repair workshop, it should have certain equipment for the tasks that are normally carried out in it. There should be a central or easy-to-access-area for the tools, machinery and instruments most often used in order to reduce unnecessary movement of the operators and improve the productivity of the whole. The most usual resources that we can find at the work positions are:

- Workbenches and transport trolley
- Conventional manual tools
- Specific manual tools
- General use equipment
- Electrically or pneumatically powered tools
- Electronic measurement and diagnostic equipment

Depending on the speciality of the workshop in question, it will also have special equipment for the performance of its work such as: machinery for tyres and steering adjustment, AC equipment repair, radiator repair, audio and multimedia, repair of petrol and diesel injection components, etc.

RECEPTION AND COMMUNICATION

Communication

Communication is the process of transmitting or exchanging messages between a sender and receiver. For this to be possible, it is essential that between the sender and receiver, for example, between the technician and the customer, there is a common interpretation or understanding on the code that they are using, otherwise the content of the message would not be understood.

In the workshop working environment, special attention must be paid to the communicative action as success or failure can depend on this when dealing with a potential customer. The information provided by good communication with the customer will be a great help during the vehicle's diagnostic process, thus facilitating the resolution of the issue more quickly and accurately.

In the field of fault diagnosis, there are two main types of communication:

- Communication with the customer
- Internal communication between employees

Communication with the customer

Customer service is a situation involving interpersonal communication. A friendly reception requires an open attitude and allowing the customer to calmly describe the problem with their vehicle. The receptionist or technician must ask the appropriate questions to the customer in a comprehensible, organised and precise way in order to better clarify the information and obtain sufficient data to be able to start the diagnostic process.

Internal communication between employees

It is a mistake to think that internal communication is a luxury and something exclusive to large companies, since market demands lead to the continuous renewal of personnel in the work centre. This makes it one of the great challenges for the success of companies.

Good communication between employees is a great help during the diagnosis and repair of the vehicle, as good communication habits between operators in different sections means that information is not diluted in the different stages of the repair.

Good internal communication does not simply consist of good dialogue between colleagues or sections, but also refers to the accuracy of the written information on the repair order, essential for an accurate intervention on the vehicle.

Interaction with the customer

As we have mentioned, a good diagnostic process starts when the vehicle is received. The main task of the receptionist, or failing that the technician, when faced with a vehicle that has a running problem, is to ask the customer the reason for their visit to the workshop.

They must ask a series of questions that will enable the technician to make a preliminary diagnosis of the vehicle, offer a first indication on the nature of the anomaly and then be able to reproduce it. The questions asked must be logical, succinct and direct, as the aim is to obtain accurate information on the problem and the situations in which it occurs, such as: environmental conditions, vehicle speed, state of the roadway, system operation, etc.

Below are examples of typical questions for the customer in the event of a fault that affects the performance of the engine:

- What is the problem?
- Does it happen to you?
- Since when?
- Have you looked to see if the water and oil levels are correct?
- Does it happen when the vehicle is cold or hot?
- Is there a noise? If so, what is it and where does it come from?
- Does the car slow down?
- At what speed does the problem occur?
- Where do you think it does it most often?
- Is it very common?
- Would we be able to reproduce the problem now?

Good communication with the customer helps to detect the fault effectively and quickly repair

Reproduction of the problem with the customer

After the customer has finished describing the running faults in their vehicle and has answered the questions asked by the technician, an attempt should be made to reproduce the problem described by the customer with the aim of pinpointing the affected component or system. Is advisable to carry out a first test with the customer, as they could help to reproduce the problem more easily. During the reproduction of the problem, all the possible variables should be taken into consideration while carefully attempting to observe the dynamic conditions of the vehicle, the type of roadway and even the driving style, among other things.

After this preliminary analysis, the problem can be determined or classified in three states of varying seriousness:

- Real issue: This is an existing fault that causes the malfunctioning of the vehicle or one of its components.
- Issue due to improper handling: A fault has occurred in one of the vehicle systems or components, whether related to the engine, comfort, entertainment, etc. due to improper use or handling by the user.
- State of the art: Perception of abnormal behaviour of one of the vehicle systems by the customer. After verification and reproduction of the problem, it can be seen that the operation of the system corresponds to the state of the art and its performance is as it should be, but it does not meet the expectations of the user.

If the issue is a result of improper handling or related to the state of the art, the technician should inform and instruct the customer on the correct way to operate the component in question.

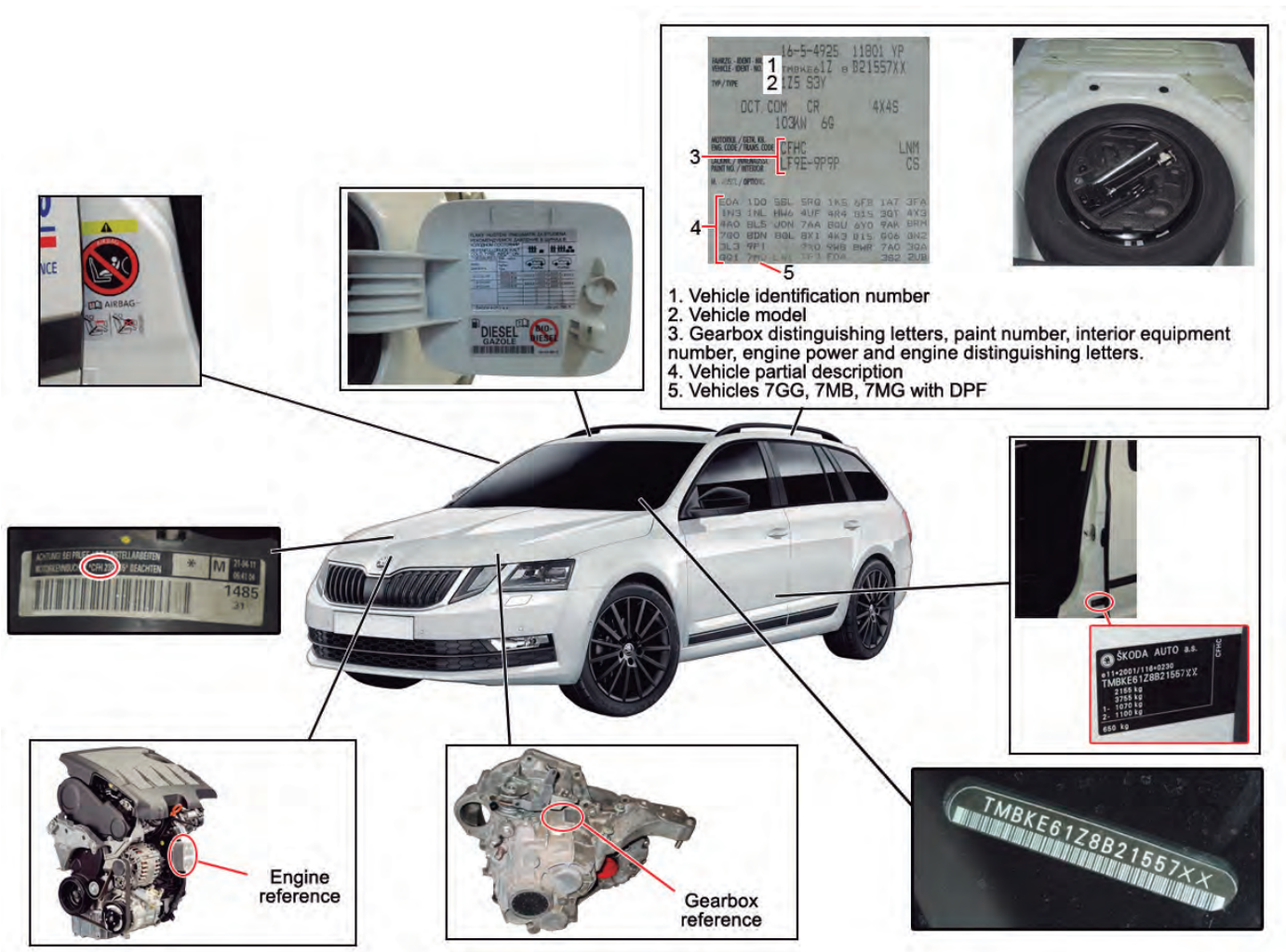
DATA COLLECTION

Vehicle identification

The first thing that the technician must do with the customer's vehicle is to identify it correctly. The correct identification of the vehicle (model, version, type of engine and equipment) is an essential factor that makes it possible to carry out the subsequent diagnostic phases efficiently and make the correct repair.

An incorrect identification could lead to mistakes in the testing and adjustment data, wrong diagnosis of components, non-compatible spare parts, etc. This negligence can result in delays to the repair, loss of efficiency, financial losses, loss of confidence by the customer, and even legal consequences in the worst of cases.

Usual identification points in the vehicle



The information that identifies the vehicles, components and other relevant data can be found in different locations.

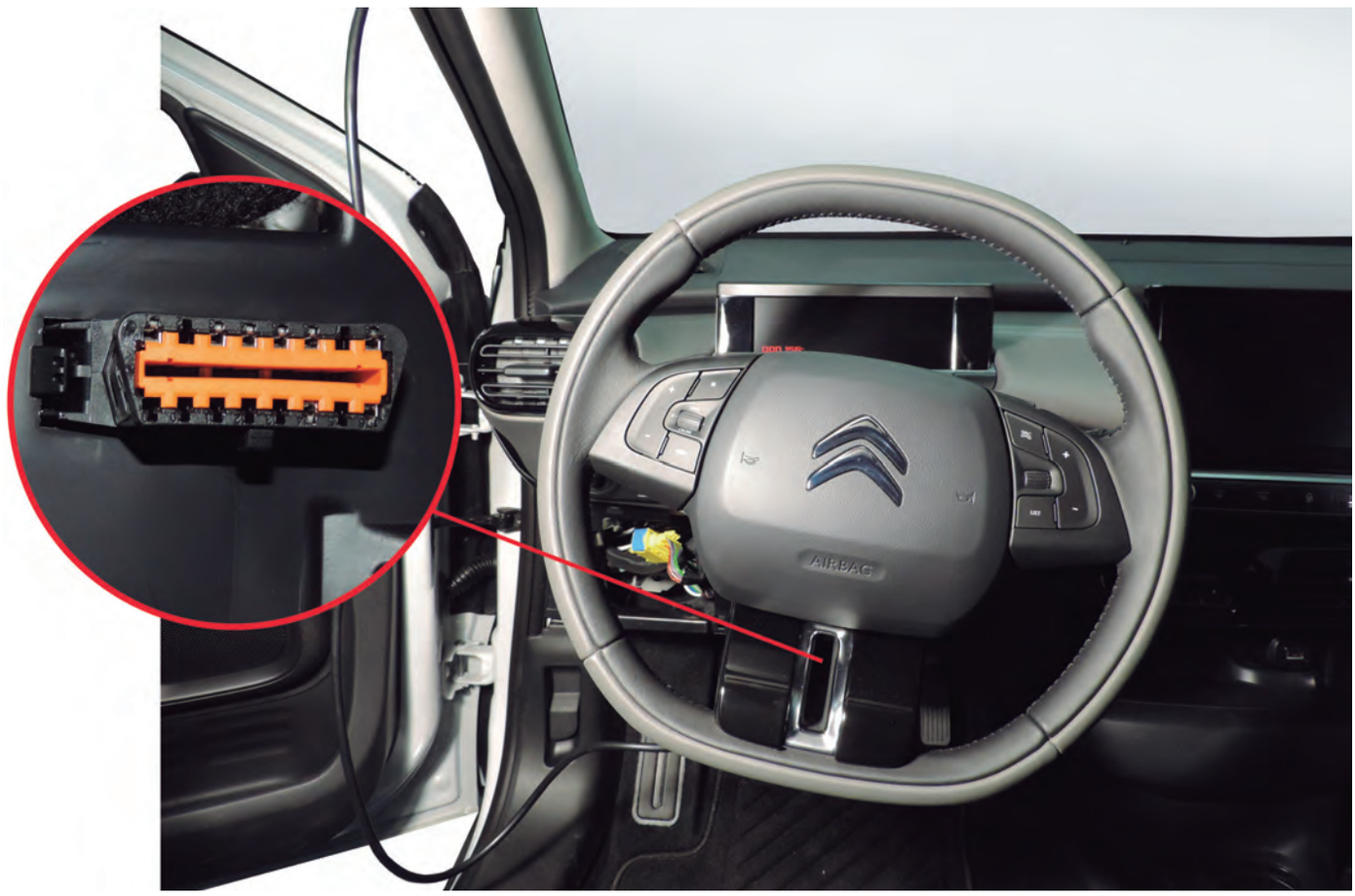
The technician must make sure that the main information on the vehicle's documentation, technical data sheet and registration certificate match the vehicle in the workshop. Among the most important information is the registration number (on the registration certificate) and the chassis number or VIN. This latter provides exclusive information on the production unit, and it is usually found stamped directly on the vehicle chassis, on the manufacturer's plate or sticker, or recorded on the windscreen of more recently produced vehicles.

Fault memory

Some electronic systems in vehicles have an integrated self-diagnostic function that automatically verifies the status of components and the correct performance of their functions. The system's control unit monitors the validity of the parameters and their coherence in order to record possible anomalies in the fault memory. This function uses a predefined coding called DTC (Diagnostic Trouble Codes) to identify the defective component or function and even the nature of the detected fault. To consult the fault memory, a diagnostic tool is essential. In general, these instruments have two working modes:

- EOBD: the diagnosis is carried out by means of a standardised protocol that manufacturers must comply with. It allows the operational status of the vehicle's safety and anti-pollution systems to be consulted.
- Specific: the diagnosis is established by means of the manufacturer's specific protocol on any vehicle system compatible with the diagnostic tool used. It allows the working parameters of the analysed system to be consulted, fault reading and the adaptation/programming of components or functions.

In both cases, the diagnosis is made through the vehicle's diagnostic connector which is standardised for the European market in format and location of the connector for vehicles marketed since around the year 2000.



The electronic communication protocol is the set of defined methods and rules that allow communication and the division of information between one or more devices.

DTC Code interpretation

DTC fault codes have an alphanumeric format and can be divided into two types: standardised and non-standardised. Standardised, for example, are formed by five characters, the first is a letter followed by numbers. The initial letter refers to the type of system that contains the fault and the following numbers specify the nature of the detected error. The meaning of each digit is given below:

First digit: Identifies the affected system with a letter.

- Pxxxx: "Powertrain" error codes that relate to the vehicle's drive system, including the engine, transmission and drive.
- Bxxxx: "Body" error codes that relate to the vehicle's safety and comfort systems, such as the airbag, central locking, climate control, etc.
- Cxxxx: "Chassis" error codes relating to the vehicle dynamics and the chassis such as the brakes, suspension, stability control, etc.
- Uxxxx: "Network" error codes relating to communication between electronic modules, whether produced by defective communication lines or by the inoperative status of the electronic units involved.

Second digit: Indicates if the fault code is the standardised type (EOBD) when the digit is "0", or if it is the non-standardised type (specific) when the digit is other than "0".

Third digit: Indicates to which part of the control system or subsystem the fault code belongs. For the engine control system they are as follows:

- P01xx: Air or fuel control
- P02xx: Air or fuel control
- P03xx: Ignition system
- P04xx: Anti-pollution systems
- P05xx: Adjustment of idle speed
- P06xx: Engine control module (ECM) and auxiliary outputs
- P07xx: Gear change or traction control

Fourth and fifth digit: Contains the specific identification of the anomaly.

The detection of a fault in a specific component can be due to the defective state of the element itself, its connector, the wiring or even inside the control unit. It is important to carry out all the necessary tests before replacing a component and bear in mind all the possibilities that can lead to the detection of the same error.

The storage of certain fault codes may be accompanied by the illumination of a warning light on the instrument panel, while other codes do not display anything. It is advisable to read the DTCs even if there is no active warning light.

The faults present in the memory can have different statuses:

- Cleared fault: An old fault that has been repaired or not detected again after clearing the memory. On completion of the diagnosis, it will disappear and will not be visible.
- **Static or active**: A fault that is stored in the unit and is detected at the present moment. It cannot be cleared until the problem is rectified.
- **Sporadic or fugitive**: A stored fault that is not currently detected, but remains stored in the control unit until it is manually or automatically cleared.

Some faults are recorded together with the status of the system at the time of their detection. This extra information is called "freeze-frame", it is a great help to the technician as it provides the working conditions of the vehicle at the time of detection of the problem: engine rpm and temperature, vehicle speed, accelerator position, etc.

Depending on the anti-pollution regulations approved for the vehicle, there are conditional faults that are stored in a second memory register that do not allow forced deletion when the DTCs are cleared. These codes in the second register are called "readiness codes" and provide information on certain interventions carried out recently (clearing the DTCs, battery disconnection, time and distance of the last operating cycle, etc.). The system's readiness is updated only when the work conditions programmed for this are met.

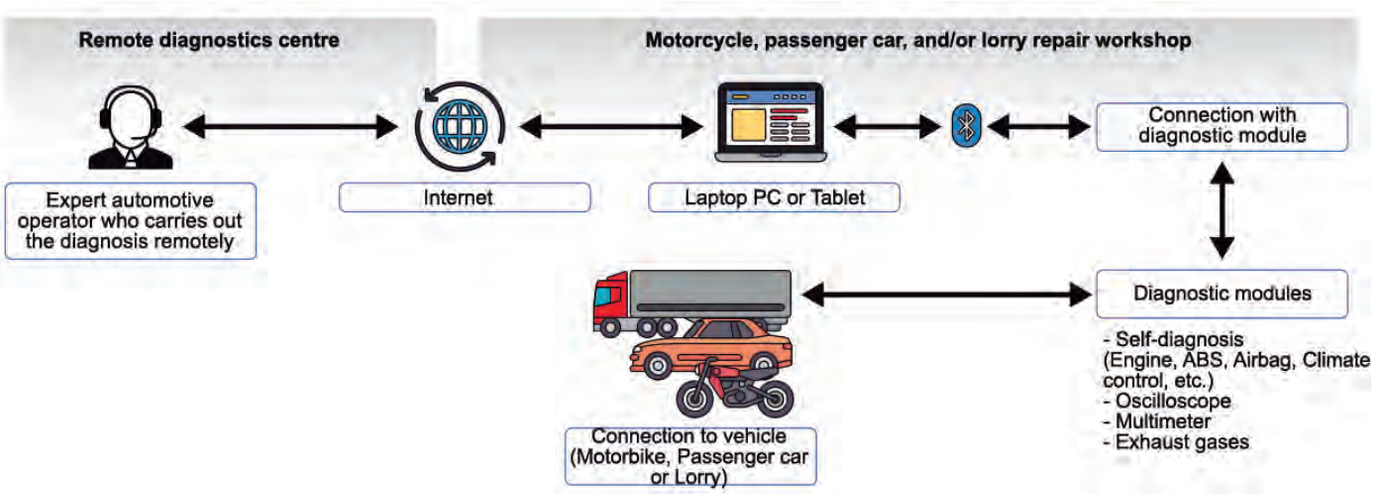
Information and technical support

The large number of manufacturers and diversity of models of vehicles currently on the road, together with their constant technological evolution, makes diagnosing and repairing the large range of faults that arise difficult. This is because it would require having technicians with full training in all the systems that different vehicles may be equipped with, in addition to having free access to the technical information of all the manufacturers (disassembly and assembly processes, electrical diagrams, values, component location, etc.) and knowing the way in which it is structured and distributed.

Given the impossibility of having all these resources for obvious cost and profit reasons, there are specialist companies that offer information and technical support services to the workshop that help it solve the problems related to its vehicles. This service links personnel who specialise in different brands and technologies with workshops through a telematic support system or Call Centre. The workshop obtains the necessary technical support to optimise repair times at an affordable cost, thus improving the efficiency of the work and the profits for the business.

What is obtained from good technical support?

- Electrical diagrams
- Technical notes
- Repair instructions
- Remote diagnostics with specialist technicians
- Reference values and other data
- Component location
- Guidance on the repair
- Interpretation of error codes



When requesting the necessary technical documentation, it is advisable to have the information ready that the call centre or technical support service may request:

- Complete identification data of the vehicle
- Symptoms of the problem
- Tests carried out and results obtained

TESTS AND VERIFICATIONS

Dynamic tests

The purpose of driving tests on different routes and surfaces is to reproduce the dynamic conditions in which the anomaly described by the customer occurs (noise, buzzing, vibrations, power problems, pedal feel, handling smoothness, etc.), or to verify the correct operation of a system or element in the vehicle as safely as possible (brakes, dampers, steering, driver assist system, etc.).
The test must be carried out with a clear objective and methodically so the operation of the vehicle is sufficiently tested for the detection of the damaged or deteriorated elements that are not performing their function. As previously mentioned, the customer's explanation must be taken into consideration and an attempt made to reproduce their driving style, while paying special attention to small details such as, for example:

- The speed at which the anomaly occurs.
- If the anomaly occurs when the vehicle is at service temperature or cold.
- The usual routes.
- If the vehicle travels loaded or unloaded.
- The engine working speed.

After the diagnosis and repair, it is advisable to conduct another dynamic test on the vehicle with the same characteristics, which will confirm if the vehicle anomaly is still present or has been rectified correctly. The confirmation of a successful repair avoids the customer returning for the same reason.

Visual inspections

The purpose of a visual inspection is to locate signs of poor condition and possible deficient operation of a system or component, generally when the vehicle is stationary. Based on the symptoms described by the customer, the technician should orientate their initial inspection towards the area or areas where the cause is most likely (cabin, boot, engine compartment or its underside, among others), and carry out the necessary steps for a sufficiently detailed visual inspection.

The use of torches, inspection mirrors for inaccessible locations and even mobile telephone cameras is very usual in these operations, as is the use of levers for checking play. The removal of lining covers or the lifting of the vehicle may be necessary to achieve a more comfortable or simply adequate view.

The most frequent anomalies found during the visual inspection are:

- Leak: this is the loss of fluid from a component or between two elements of a circuit due to wear or lack of leak-tightness (losses of engine oil, coolant, steering fluid, brake fluid, refrigerant, etc.).
- Breakage: this is when a body suffers damage or a fracture caused, generally, by an impact or excess mechanical force.
- Deformation: this is the alteration of the shape of the body caused, generally, by a knock or excessive working temperature (warped disc, twisted suspension or steering arms, deformed parts of the chassis or body, etc.).
- Wear: this is when a body or part of it has been consumed through use or continuous friction (wear of brake pads, discs, tyres, belts, etc.).
- Obstruction: this is a hindrance to the flow of a fluid through a line or opening (obstructed expansion valve, engine radiator with dirt in its fins, EGR dirty, etc.).
- Disconnection: this is the accidental interruption of the joint between two bodies. Generally it refers to the electrical (unit connectors, unplugged sensors or actuators, poorly connected fuses or relays, etc.), hydraulic or pneumatic communication between two elements.
- Deterioration: this is when a body goes to a worse state or condition generally caused by fatigue, wear or contamination.

There are many anomalies that can be located statically after their detection in the dynamic test of the vehicle. Play in the running gear, for example, can be detected by sound when moving and then located after elevation and visual inspection of the vehicle. Remember, in both situations, to try and reproduce the problem once the affected part or component has been replaced in order to confirm that the described problem has been resolved.

DIAGNOSTIC EQUIPMENT

Equipment specifications

The evolution of mechanical control systems to electromechanical control systems first and then to electronic ones involves the incorporation of new components, the diagnosis of which can be complex and unreliable if the necessary means are not available. One of these means, and probably the most important, is the diagnostic tool, which is now an essential instrument for analysing the correct operation of the various vehicle systems.

The possibilities of the electronic diagnostic tool are not limited to reading and clearing DTCs (EOBD or specific) but, depending on its compatibility with the vehicle, it also allows the real-time display of the data provided by the sensors, the parameters calculated by the control unit, the output signal supplied to the different actuators, the activation of certain components, the update of the working software of the unit and other settings. Knowledge and use of these tools are crucial in many cases to distinguish between mechanical and electrical malfunctions, and is essential for setting certain components after replacement, either due to changes in the design of the components, resetting of values stored in the control unit, or simply to set the initial parameters to conform to manufacturing tolerances.

Parameters and statuses

Parameters

A parameter is data that allows a certain situation to be analysed and understood. The parameters displayed by the diagnostic tool reflect real-time information on the various sensors, calculations and actuators with which the vehicle's control unit works. The interpretation of the data enables the determination of whether the data that the unit receives corresponds to the related physical variables, and if the system or component is affected or not by the detected faults.

Depending on the technological evolution of the control unit and the complexity of the diagnosed system, a large number of parameters can be displayed, which can be real, calculated, or target. It is important to select and focus on those necessary for the repair or the test that you want to carry out. The information available through this function can be displayed in the working electrical magnitude of the unit or in the corresponding physical/logical value, in different measurement units,

such as for example: power (W), pressure (bar, mbar), temperature (°C), speed (rpm), injected fuel mass (mg/c) voltage (V, mV), current (A, mA), etc.
Depending on the diagnostic equipment used, the parameters can also be displayed graphically as a function of time. In this way, both the absolute values can be analysed as well as their evolution over a certain period of time in order to verify that it is logical and coherent with reality.

Real values and target values

Modern control units work both with calculated values and with values stored in three-dimensional maps, which allows some real parameters to be compared with their theoretical equivalents. For certain functions and actuators, these theoretical values are displayed as a target value, i.e. the value which the control unit aims to reach or should obtain in accordance with current working conditions. The real values are those measured and read at that same instant that always corresponds to a calculation, control signal or electrical input magnitude to the control unit. When the real value is different from the theoretical or target value, it could be due to a real work defect (failure of the component or related system) or a measurement problem (it is not measured correctly).
The analysis of the real values is one of the most used methods in fault diagnosis. It is a very effective testing technique when error codes (DTC) appear related to a specific sensor or actuator.

Status

In this section the status of some signals, functions and activations related to the electronic management of the system is displayed in real time. Many of these correspond to activations that must be made by the driver or logically determined by the control unit depending on other variables, therefore, to check the change of status, some conditions must be met or certain actions carried out. The check always consists of verifying the change between the two possible logical values that are displayed in various ways, the following being the most common:

- Open, closed
- Active, inactive
- 0 or 1
- Actuated, not actuated
- Stopped, started

Activations

Electronic control units allow the activation on demand of many of their actuators. The temporary activation of the elements that must carry out physical work through the diagnostic tool allows the testing of the correct functioning of control components and their electrical lines with the vehicle in static conditions. The working tests can be carried out using a visible or audible method, and those of the governing signal can be carried out by oscilloscope or multimeter. The activations are very useful for the diagnosis as they allow the display, prior to their disassembly, of the work of components normally hidden from view or, due to their function, only work when the vehicle is moving or working in very specific circumstances.

It must be remembered that there are malfunctions of certain components that cannot be recorded as faults (DTC) as there is no possibility of electrical testing of the work carried out (feedback). The activation function is only valid when:
- The control unit is capable of activating the component.
- The wiring between the unit and the actuator is in good condition.
- The component is receiving an electrical power supply.
- The actuator is capable of operating when the unit requires it.

Regulation and codification

The options in this section allow permanent modification (programming) of the software and the data stored in the control unit, for example: clearing the adaptive parameters, modifying the idle speed, coding the injectors, selecting the available equipment. etc.

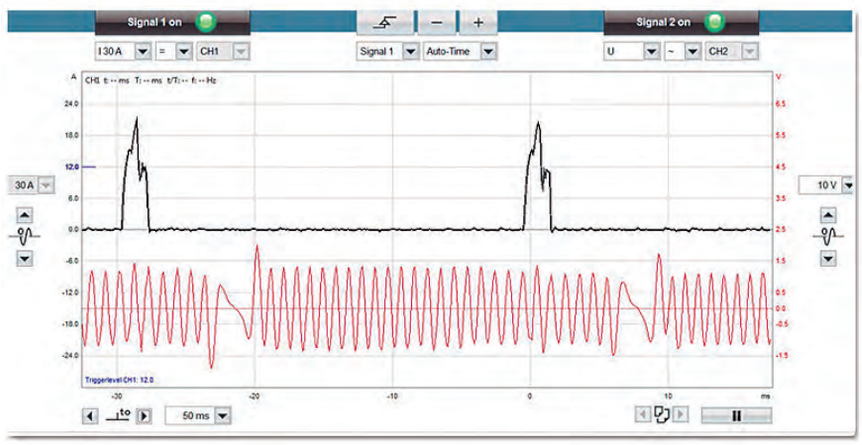
Special attention should be paid to the configuration of the units, as an operating error could cause malfunctioning of the system, the vehicle ceasing to comply with the legal requirements of its approval and even the appearance of DTCs. The working program of the diagnostic tool usually displays warnings in this regard before carrying out the operation, and in many cases requires the acceptance of a conditions document in which the technician takes responsibility for the modifications they make and their possible legal consequences.

Some specific units and settings, normally related to safety or vehicle performance, require the entering of an authorisation code. The “special code” is a code created by the manufacturers to reserve for their distribution chain certain advanced settings that are not associated with the repair or maintenance of the vehicle. Normally they are control unit functions that are disabled or hidden by the manufacturer (cruise control, coming home lighting, automatic folding of the rear view mirrors, etc.) which are used to configure the vehicle in the production chain. They also allow the adaptation of software to the vehicle’s destination market, due to variations in fuel, climate, raising the idle speed in vehicles with a hydraulic system for tippers, enabling/disabling transport mode, etc.

The possibility of replacing a component, modifying parameters or configuring a new control unit has different levels of difficulty. This will be expressed in two protection levels:
- The first level is for enabling the standard settings such as: maintenance reset, the reset of an electronic counter, the entering of the injector code when it is replaced, etc.
- The second level is focused on the complete programming of the software, the legal and/or safety settings, i.e. any programming that could cause damage, result in hazardous situations or the vehicle not complying with legal regulations. An Internet connection may be necessary at this level.

OTHER SPECIFIC EQUIPMENT

Oscilloscope



The oscilloscope is a measuring instrument that graphically displays any electrical signal and its variation over time on its coordinate axes. These coordinates are called “y” for signal voltage and “x” for signal time. Its use is increasingly required for the diagnosis of electrical and electronic systems. Basically, there are two types of oscilloscopes on the market: analogue and digital. The latter have replaced the former as they are more economical and have greater work and screen display flexibility.
Oscilloscopes have numerous functions and controls for configuring the equipment according to the different electrical nature of the analysed signals (sine wave, PWM or square, triangular or sawtooth, etc.). The technical details of the equipment usually vary between manufacturers and models, nevertheless, they all have some common controls to facilitate the configuration of the equipment for the representation of the signal on its screen, such as:

- Reference line position
- Volt/division (V/d) scale
- Time/division (T/d) scale
- Trigger

Depending on the type of oscilloscope, it may have 2, 4, or more channels for analysing several signals from the vehicle simultaneously, for example: the operation of all the fuel injectors, the correlation between the phase sensor and the engine rpm sensor, mass air flow control and the turbo pressure, the fuel flow regulating signal together with that of the fuel pressure sensor, the speed signal from two or more wheels, etc.
The oscilloscope terminals can be connected to different types of test probes (crocodile clip, needles for connectors, piercing clips, etc.) for the measurement of the signal voltage. For the measurement of other magnitudes required for the diagnosis, such as current or pressure, there are other specific adapters that convert the parameters that you want to display into a proportional voltage.

Multimeter

This is an essential tool for measuring and testing several electrical magnitudes, and is also known as a multitester. It is therefore indispensable for the diagnosis of electrical and electronic systems and components in vehicles. In the automotive sector, it is used for measuring voltage differences, currents, working frequencies and electrical resistances among others, for the testing of signals, electrical power supplies and the status of many components.
The first multimeters were analogue and very limited, which is why they were replaced by digital meters which are more accurate and offer more measurement options and greater measurement ranges. Digital multimeters of various types can be found on the market, among which are meters designed specifically for the automotive sector that include certain functions relating to combustion engines, such as the measurement of engine rpm, work cycle percentages, injection time, temperature tests, etc.

Temperature measuring devices

The thermometer is an essential testing and diagnostic tool for certain vehicle components whose work depends on temperature or whose temperature can be seen to be affected in the case of a fault or malfunction. Contact thermometers can be used in the automotive sector for measuring fluids, gases and moving substances, and contactless thermometers can be used for measuring the temperature of solid or stationary components.

Contactless digital thermometer

Also known as an infrared pyrometer, it is used to measure the temperature of the surface of objects without requiring direct contact with them. With the help of a laser pointer, infrared light is projected onto the measurement surface which rebounds and returns to the equipment. The thermal radiation emitted by the object is incident on a sensitive resistive sensor, which gives rise to an electric current from which the temperature is calculated by an electronic circuit.
The infrared pyrometer only measures reflected radiation and not the temperature itself. The energy emitted by the object or its absorption is used to calculate its temperature. The colour of the reflecting surface has an influence in this regard.
It should also be noted that these types of thermometers can only be used reliably on smooth or uniform solid surfaces. It is understood that the temperature of a base that is liquid or too rough cannot be measured with sufficient accuracy, as the infrared light is not adequately refracted. The cleanliness of the measurement surfaces and free access of the infrared light to them must also be taken into consideration.

Examples of applications of the equipment

- Diagnosis of the air-conditioning system (temperature control in the circuit pipes and mechanical components, vents, etc.) and performance of the engine's cooling circuit.
- Verification that the temperature sensors are working correctly (by comparing the measurements of the diagnostic parameters with the real temperature).
- Diagnosis of the operation of components that carry out continuous work (looking for possible overheating).
- Checking for damaged bearings and braking imbalance.

Digital thermometer with contact

This type of thermometer measures the temperature of the body or substance by direct contact, by means of an NTC type temperature sensor located on the end of a rod. It takes accurate temperature measurements in liquids and gases and can be used for measuring the temperatures of oils, coolant, air in the cabin vents, ambient temperature, etc.

Pressure equipment

Manual pressure/vacuum generator and tester

This is an instrument designed for generating and measuring pressure or vacuum in the pipes of low-pressure pneumatic or hydraulic circuits (0-10 bar). It is suitable for testing both actuators and sensors by comparison with reference data or diagnostic parameters. It is used for the diagnosis of:

- Air intake pressure sensors (MAP)
- Turbocharger wastegate valves (boost pressure)
- Fuel pressure regulating valve (low pressure petrol engines)
- Servo brakes
- Intake manifold pressure
- Leaktightness in the engine cooling circuit
- Pneumatic flap valves

It consists of a mechanical piston pump, manual actuating mechanism, a reversing valve for generating pressure or vacuum, a pressure gauge and a measurement outlet which can be connected by means of different adapters to the component or circuit to be diagnosed. Repeated manual actuation produces the pressure or suction necessary for the work of the actuators. The pressure value can be read on the pressure gauge at all times.

There are devices of this type that only measure and produce positive pressures (above atmospheric) or negative (below atmospheric) and others that include receptacles for transfer of liquids or flushing by suction.

Example of equipment application

Coolant leak testing

A drop in the coolant liquid level could be due to a loss or leak at some point in the coolant circuit. The pressurisation of the engine's coolant systems increases the boiling point, but also makes it difficult to locate particularly small leaks. To carry out the complete inspection of the circuit without the need to keep the engine running and hot, a specific tool can be used which generates pressure in the coolant circuit when the engine is cold.
The leak tester is connected on the expansion bottle in the cap position. It has an air pump and several adapters of different diameters. The usual working pressure of the coolant circuit is 0.6 to 0.8 bar (relative pressure). The leak tester generates and maintains pressure slightly higher than the working pressure, around 1 to 1.5 bar, which increases the leak flow to help in its detection. Once the testing pressure is reached, observe the pressure gauge and verify that the value remains stable or otherwise goes down indicating the existence of a leak in the circuit. If the pressure falls, the coolant leakage point should be located and repaired.

When locating leaks, be aware of the hidden areas of the coolant circuit, especially the heating radiator and the internal part of the engine. As regards the latter, the coolant may mix with the oil, leak into the exhaust, the intake or the combustion chamber. In all cases, the accumulation of coolant expelled when the engine is stopped allows the problem to be located by removing the manifolds, spark plugs or the glow plugs, which is impossible to do with the engine running and therefore to diagnose effectively.

Digital pressure tester

This instrument is capable of measuring several pressures simultaneously or memorising measurement sequences, by means of different sensors that provide different measurement ranges of greater and lesser accuracy. Depending on the equipment and its accessories, a large number of specific tests can be carried out in a guided manner, for example:

- Compression testing of cylinders in diesel/petrol engines.
- Testing high/low common rail pressure.
- Measurement of the oil pressure at several points in the circuit.
- Checking of the pressures in the hydraulic braking system.

The equipment programming allows both the predefined tests and continuous free measurement to be selected, as well as the display of the data in several numerical and graphic formats. Some devices even record the test and store the measurement data for later detailed analysis, which is ideal for intermittent faults and dynamic tests or the presentation of the results.

Optical equipment: endoscope

The endoscope is used to visually check components that are difficult to access by means of a small camera and a screen without the need for costly disassembly. In this way, a rapid but substantiated diagnosis can be carried out on the condition of certain internal components and their possible impact on the operation of the vehicle. Basically, the device consists of a semi-rigid tube with the camera and a small lens on the end that can be inserted into small holes and cavities. The captured image is displayed on the equipment's screen through a connected monitor. There are several options on the market with different physical and technical characteristics. Some of these have a camera zoom control, allow images to be recorded and even allow them to be reproduced wirelessly.

Most common uses of the endoscope in the automotive sector

The main application of this tool in the automotive world is the internal inspection of the engine cylinders through the holes of the injectors, spark plugs or glow plugs, gearboxes, differentials, etc. In this way, defects of pinions, forks, valves, pistons or the condition of the sleeves can be observed for a preliminary diagnosis of the scope of the mechanical faults in the engine or transmission.

Nearly any part of the vehicle that is difficult to access can be displayed, which also makes it ideal for the detection of liquid leaks, inspection of climate control flaps and even the location of hidden fasteners and fixing clips on panels and upholstery.

Noise tester: stethoscope

This tool is designed to verify abnormal noises or vibrations that appear in different moving components of the vehicle. Generally, two types of stethoscopes can be found: mechanical and electronic. The mechanical stethoscope is principally made up of:

- A steel rod or probe -1-
- An amplifier chamber -2- which incorporates a metal membrane -3-
- Flexible tubing -4- with earphones -5-

Physical contact between the end of the probe and the external surface of the component to be verified transmits possible vibrations through the rod metal to the amplifying membrane where it is converted to acoustic pressure variations. These are then channelled through the tubes to the earphones. In this way, the vibrations that are transmitted through the metal are converted into easily perceived acoustic frequencies.

Exploration with the end of the rod over different areas of the same component enables the origin of the noise and therefore the anomaly to be located. This is nearly impossible in any other way, as the vibrations are transmitted by the metal in every direction and then to the air, forming the sounds, through the irregular and in many cases continuous surfaces. Furthermore, particularly around the engine, the frequencies of numerous sound sources are combined, preventing any differentiation. The stethoscope's earphones isolate the technician's ears from the environment, thus preventing the perception of frequencies outside the probe contact area.

Electronic stethoscopes have a greater noise amplification power than the mechanical type, therefore they can be more effective. The vibrations perceived by one or more sensors are filtered and amplified in an electronic circuit, and then converted into sounds by means of earphones. The remote installation of the sensors, with their connection by wire to the amplifier and the possibility of using several simultaneously, multiplies the diagnostic capacity of these types of stethoscopes. They can also be used in dynamic tests for locating noise in the suspension and transmission of the vehicle.

It is important that the technician has prior knowledge on the operation and sounds of the component to be verified, an essential requirement for recognising and diagnosing the possible defective state of the component. For example, if the technician suspects that the sound heard in the timing area could be due to the poor condition of the water pump, the tensioning roller of the serpentine

belt or even of a timing chain tensioner, the only way of effectively locating the defective component without dismantling is to use the stethoscope. The normal sound of these three components is very different, so they cannot be compared. The water pump sound is a low buzzing, the belt tensioning roller emits a fine and uniform whistling, and the chain tensioner has a dull and rhythmic vibration. Any anomaly in the tone or variation in the sound pattern indicates the defective condition of the component in question.
The stethoscope is very useful for checks on operation and anomalies or noise from, for example:

- Injectors
- Timing chains/belts and their components
- Alternators
- Water/fuel pumps
- Wheel bearings
- Bearings
- Cracked manifolds
- Solenoid valves

For injectors and other repeated elements such as wheel bearings, the diagnosis of defects by comparison is quick and easy.

LOGICAL WORK SEQUENCE FOR THE DIAGNOSTICS PROCESS

Logical work sequence summary

When a vehicle goes to a workshop with a fault, doubts about its repair and cost are more likely if there is not a specific and accurate diagnosis. Having the necessary means and knowledge together with a logical work sequence allows the diagnosis to be made confidently and efficiently, optimising the repair times while conveying a sensation of professionalism which converts into customer confidence. As regards the necessary instruments, the following diagram summarises the steps to take for a correct and logical work sequence.

Communication and identification

- Interaction with the customer
- Reproduction of the problem
- Vehicle identification

Information and repair

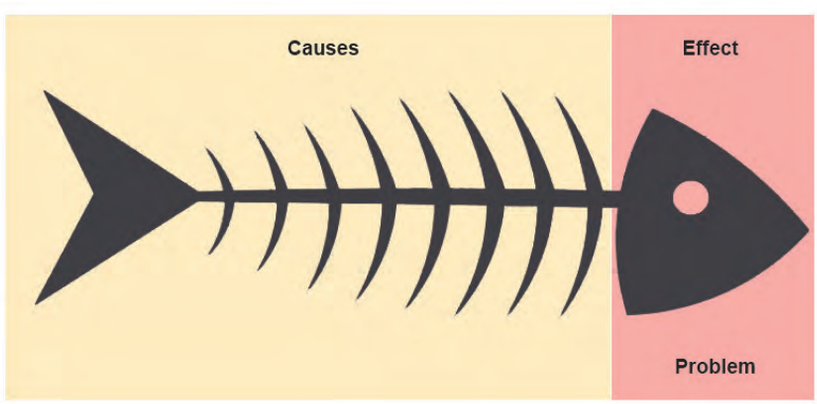
- Diagnostic equipment
- Collection of technical notes
- Verification of the affected system
- Repair and adjustment
- Dynamic or manual test

Diagnostic sequence: Ishikawa diagram

The logical diagnostic sequence is a set of ordered processes that enable the anomalies present in the vehicle to be detected, as well as their causes. One of the most efficient methods for carrying out this task is that proposed by the Japanese doctor Kaoru Ishikawa in his cause-and-effect theory or diagram, also known as the Ishikawa diagram or the fishbone diagram.

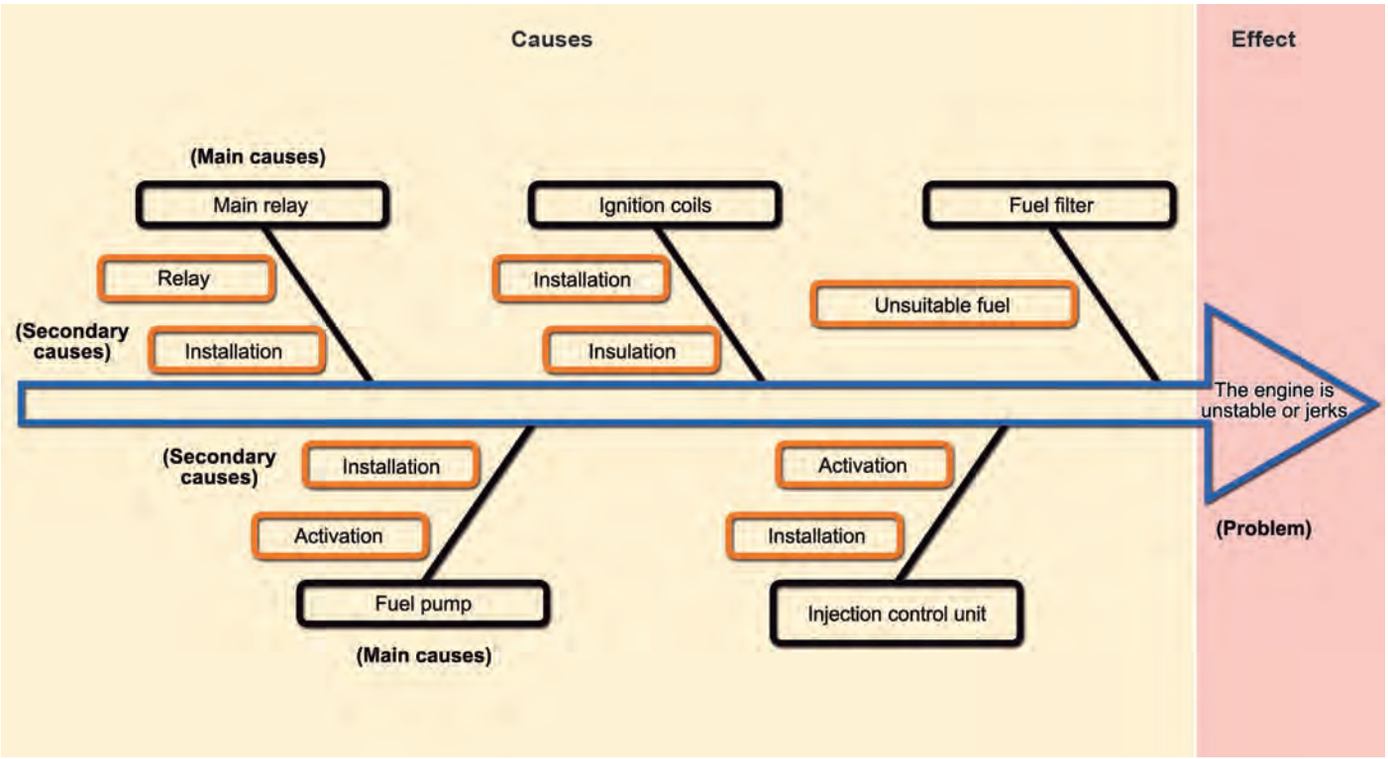
The diagram is used to graphically represent and organise all the knowledge that a group or individual has on a problem or topic in particular, which in effect are the resolution possibilities. In this way, it is easier to identify, set out and classify the possible causes, both for specific problems and for quality characteristics or operating problems. The diagram graphically illustrates the relationships existing between a given result (effects) and the factors (causes) that influence this result.

Kaoru Ishikawa (1915 - 1989)



How the diagram works

The Ishikawa diagram is constructed from right to left, the fish head represents a problem, for example the engine is unstable or jerks, while the bones are the various categories on which the potential and secondary causes are grouped that could be the origin of the problem (main relay, fuel pump, coil installation, etc.).



Fault repair order

The initial graphical depiction enables the subsequent ordered diagnostic sequence of the testing tasks to be carried out while considering different criteria such as the probability (according to repeated experience), the availability of testing means and even the relative cost of the necessary verifications. The following aspects must be considered:

- Knowledge of the system or component.
- Availability of tools or instruments necessary for a reliable test.
- Intervention time for testing or approximate cost.

Each one of these factors for consideration will receive an initial rating of 10 points that must be reduced according to lack of technical knowledge, lack of the necessary means for testing, or difficulty/costs of this. The highest result of the sum of the three variables will determine which component or factor must be checked first, and then continuing with the others in order of their rating. The relationship of the three criteria used prioritises the conducting of the greater number of tests at the lowest possible cost and with maximum test reliability, which results in the detection of the root cause of the problem in the most efficient way possible.

Taking the above case as a reference, the testing of the relay will always be more cost-effective, quick and accurate than the testing of the control unit, not only due to the knowledge of the component and its operation but also due to the need for tools and the associated costs (labour and direct costs).

Relay

System knowledge Operator knowledge on its operation	9
Necessary tools and instruments Tools available in the workshop for removal and testing	10
Intervention time Time invested for diagnosis of that component	10
The total sum of points out of a possible 30 points	29

Control unit

System knowledge Operator knowledge on its operation	7
Necessary tools and instruments Tools available in the workshop for removal and testing	10
Intervention time Time invested for diagnosis of that component	5
The total sum of points out of a possible 30 points	22

Fuel filter

System knowledge Operator knowledge on its operation	10
Necessary tools and instruments Tools available in the workshop for removal and testing	10
Intervention time Time invested for diagnosis of that component	7
The total sum of points out of a possible 30 points	27

Ignition coils

System knowledge Operator knowledge on its operation	10
Necessary tools and instruments Tools available in the workshop for removal and testing	10
Intervention time Time invested for diagnosis of that component	8
The total sum of points out of a possible 30 points	28

Fuel pump

System knowledge Operator knowledge on its operation	9
Necessary tools and instruments Tools available in the workshop for removal and testing	8
Intervention time Time invested for diagnosis of that component	4
The total sum of points out of a possible 30 points	21

In this case, the logical testing order will be:

1. Relay 29 points
2. Ignition coil 28 points
3. Fuel filter 27 points
4. Engine control unit 22 points
5. Fuel pump 21 points.

Conclusions

Fault diagnosis is the first step in a repair and determines the evolution of every aspect of the repair. The quotation, its acceptance and the satisfactory result of the operations carried out will depend to a great extent on the initial diagnosis. Hence, the profitability of the business starts with a good diagnosis.

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