POLITECNICO DI TORINO

Department of Control and Computer Engineering

MASTER DEGREE
IN

MECHATRONICS ENGINEERING

Didactic Test-Bench of a Vehicle's Engine

Supervisor:

Prof. Raffaella Sesana

Company Tutor:

Prof. Daniela Maffiodo

Candidato

Dionysia Varvarigou

October 2018

Abstract

A vehicle’s engine is a combination of mechanical, electical and electronic components with capabilities of converting chemical to mechanical energy. It is widely used in evey kind of transportation system, such as vehicles, trains, airoplanes e.t.c. Test-bench is a tool for anykind of testing, of any kind of device, depending on the purpose of the project. In general, it includes integrations of mechanical parts, electrical connections, embedded systems, e.t.c. Test-bench is able to lead to verification of working condition, detecting faulty components, monitoring testings for data analysis, including evolutions of devices and development of testing projects. Developing a test-bench for didactic purposes and giving the chance to the students for hands-on the engine and the testing procedure, is a challenging research project. This written thesis presents an integrated didactic and an implemented by hand research, for the collaboration of the institution Filos and Politecnico di Torino. This work comes after the already existing engine, instrumentation, actuators and ECU and their dependencies on the integration with the embedded systems, electronic components and electrical connections. The approach permits the creation of a team of three students to develop parts of this thesis. This thesis report presents the design parts, the connectors mapping, the testing procedures, data acquisition, results analysis, and a project for future work. The results show the good and defective working condition of the engine, as a tool for the students to use and to evolve.

Keywords : Test-bench , didactic , instrumentation, sensors, actuators, test-stand, embedded systems, ECU, data acquisition, data analysis, testing procedures

Table of contents

List of tables

List of Figures

List of symbols

$\dot{m}_{ai}$ → mass flow rate into manifold (g/s);
θ → throttle angle (deg);
P_m → manifold pressure (bar);
P_{amb} → ambient (atmospheric) pressure (bar);
R → specific gas constant;
T → temperature (K);
V_m → manifold volume (m^3);
$\dot{m}_{ao}$ → mass flow rate of air out of the manifold (g/s);
$\dot{P}_m$ → rate of change of manifold pressure (bar/s);
N → engine angular speed (rad/s);
P_m → manifold pressure (bar);
m_a → mass of air in cylinder for combustion (g);
$\left(\frac{A}{F}\right)$ → air to fuel ratio;
σ → spark advance (degrees before top - dead - center);
$Torque_{eng}$ → torque produced by the engine (Nm);
J → engine rotational moment of inertia ($kg \cdot m^2$);
$\dot{N}$ → engine angular acceleration (rad/s^2);

Chapter 1 Introduction

Test bench for a car's engine, is a tool for measuring and testing the operating behavior and the mechanical characteristics of an engine. We use it for locating faults and malfunctions of the engine and of the components of the engine. The test-bench itself can be built by different materials and in different constructed ways, according to the type of engine and the testings, which are required. In the present thesis an engine test bench was developed and described aiming at the study of the working principles of the engine. Thus it is a tool for:

- trainers to teach
- students to learn

In the present project a FIRE ICE[1] engine was tested. The test stand used for this testing, is a robust bench made out of steel. The data acquisition is obtained by embedded systems[2].

The term FIRE refers to the first engine that was fully integrated by robots known as « Fully Integrated Robotized Engine », which was a simple mechanical straight-4 engine, with all four cylinders placed in a straight line. At first the FIRE was a carburetor engine, then it evolved to a single point injection (S.P.I.), later progressed to a multi-point injection (M.P.I.). In addition, the latest evolution was the sequential multi-point injection (S.M.P.I.).

ICE engine is referred to an internal combustion engine, in which, the combustion between the fuel and the air occurs in the combustion chamber. This specific combustion produces a significant expansion of high temperature and pressure gases. The gases apply a force to different components of the engine to produce a mechanical energy.

In the present activity, a special focus is on the didactic part. The system has two didactic targets. The first part deals with didactic materials for the trainers. And the second, for the students. This kind of didactic materials will be able to provide to the students a tool for their understanding and hands on learning about engine working features and reciprocal parameters influences.

1.1 Background

The type of the engine and the cause of the testing can define a lot of the design process of the testbench. First, we have a wide range of materials and forms of testbenches, in order for us to construct the right testbench for the right engine. Second, the design of the extra implementations on a testbench, such as; timeplots to check the performance of the system under testing as, electronic parts, and microcontrollers used as a ECUs. Third, the choice of the appropriate software for the gathering of data, processing and analising data and, mapping them in the form accordingly to our needs.

In literature several papers are present dealing with engine test-benches, for different purposes. For example, [The Development of a Small Diesel Engine Test Bench, Employing an Electric Dynamometer], a MD thesis is dedicated to the design and development of a test bench for a small disel engine, for testing small quantities of biofuel.In [company reference: easy-run] a company created different types of teststands for various types of engines or testings (test stands with different dimensions for a wide range of engine tyoes); in [youtube: cirillo188] an amateur

1 FIRE describes the type of construction of the engine and ICE describes the type of function of combustion of the engine.

2 Embedded systems is the integration and communication of software and hardware.

developed a teststand of a vespa motor, according to the functionality that they need to pursuit their hobbies. The referred engine can be of any size and kind of engine, from a car’s to a train’s engine.

1.2 Purpose

The necessity of the project’s formation lies on the fact that we needed to create a project that will give hands on learning to consolidate the understanding of the working condition of the engine and all the other components. We have to analise the purpose of the two following parts of our project. First the part of the testbench and the whole system based on it, for testing the engine, and second the didactical part, for understanding and learning purposes. Thus, a requirement of the project is user friendliness and simplicity.

For understanding the purpose of the part that deals with the testbench and the whole system based on it we have to think that, as we said before, we need a simple system that will be able to give us the working condition of the engine. For this reason we need to analise what happens in the engine if we change some variables (thus testing) and to compare between desirable or expected results and results that we get out of the testing. It is important, to know what the behaviour of the engine is in normal or fault conditions, so that we can understand how ithe whole system of our project works.

For analising the purposes that are related to the didactical part, we first need to know the level of the students that we address to. Since we are addressing to high school students’ level we agree that we need to have a simple project for better understanding and analising. By testing the whole system, gathering data and analising it, the students will be able to create critical thinking and get familiar with analising systems according to the collected data.

1.3 Components

The project is composed by the following main components:

- The test-stand
- The engine
- The sensors & instrumentations
- Electronic & electrical parts
- Embedded systems

Test-bench is the integration of the components. The sensors are implemented in the engine, which is placed in the test-stand[3]. The electronic and electrical parts help with the functionality of the whole system. And the embedded systems are responsible of the data acquisition.

1.4 Methods

The method[4] will be presented on the following steps :

- Design of the test stand, on which all the components will be placed.
- Verifying the working condition of the instrumentation and actuators, which are selected.
- Performance of a comparison between the range of values of the working condition of the instrumentation and actuators, and the reference tables for them, provided by the lab supervisor.
- Electrical and electronic connections according to the schematics, provided by the lab supervisor, as well as the modification of them.
- Design and fabrication of other complementary components.
- « Learning » of the ECU and calibration of instrumentation and actuators
- Data acquisition, via embedded systems.
- First implementations of embedded systems for substituting the ECU.

---

3 Test-stand is only the bench, in which the engine is placed.
4 Method is a systematic procedure for fulfilling a specific target

1.5 Individual contribution

This project is developed in a team basis. A group of three students elaborated to design, and realize the didactic test bench of a vehicle's engine. The project is divided in three parts, so that each student will develop an important segment, which will be integrated with the other parts, under the supervision of the lab supervisor.

In this thesis report, it is presented the segment of the following:

- Design the test-stand in the software FreeCad.
- Calibration.
- Mapping connectors:
    i. Circuit of sensors for ECU
    ii. OBD
    iii. Fuses
    iv. Relays
- Testing procedure
- Bypassing failure of sensors
- Data acquisition.
- Results analysis.
- Project for data acquisition/logging for rpm sensor.

Chapter 2 Bibliographic review

During the early stages of developing the presented project, a research was conducted to decide the design and actualization of the didactic test bench[5]. This experimental system is composed by various components, which have been mentioned previously. One more significant addition to the previous purposes of this experiment, will be to trigger and improve the students' critical thinking.

2.1 Engine test-stand

An engine test stand is where the engine is set, in order to perform the testing process. Basically, it is a mean to keep the engine steadily, for testing and classification. Thus, it is possible to apply different kinds of operations and in many different ways, depending on the object of interest. Moreover, it is used to provide measurement outcomes of multiple physical variables.

Consequently, for designing a test stand that will be the right solution for this specific project, we have to define some parameters. The parameters are listed as follows:

- Cost, which is the parameter that defines the quality of the test stand.
- Material, which depends on the cost but also on the importance of it.
- Shape/form, which is defined by the type and the characteristics of the engine.
- Robustness, which is needed to withstand the fast changeovers and the static forces of the engine, for preventing the destruction of the test bench. But it is also needed to endure the dynamic forces and to absorb the vibrations of the engine, for ensuring the good quality of the measured signals.
- Safety measures, which add in our design, some parts that can ensure the safety between human and system during the test interaction.

The safety measures are considered only at the end of the integration of this project, because a lot of modifications needed to be done, even at the last moment.

To conclude, it is given to understand that the test stand is an important component of a test bench. Hence, the design and the application of the test stand depend on the needs and the interests of the goal of the project.

2.2 Engine

The engine is a machine, which is composed by mechanical parts. By moving these mechanical parts the power gets converted to motion. For this conversion, the following elements are some of the essential needed elements:

- the high temperature
- the electric power
- the compressed air
- the fuel.

As an outcome, this machine provides power supply to the vehicle.

[5] Test-bench is the whole integrated system of this project.

The engine used in the test bench is taken from the vehicle Fiat, model punto. The volume of cylinders is 1.2 l[6] i.e.[7], with four cylinders and four strokes[8] of piston per cylinder, and the combustion is described as internal, spark ignition. For this specific engine, the internal combustion means that as a gas, a mixture of fuel and air is used.

In addition, the engine is a combination of air and exhaust manifolds. In the figure 1, it is easily understood the way that the engine works, by combining these manifolds. As it can be seen, both of them are linked directly to the SI core of Engine.

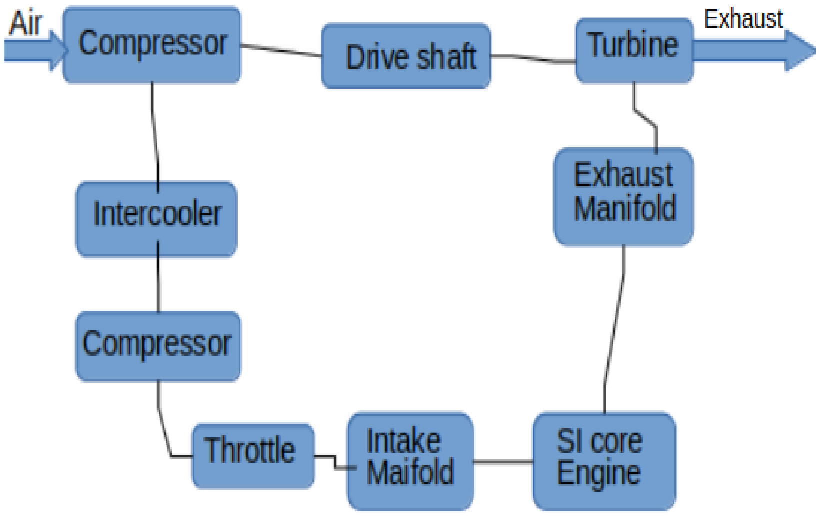


Figure 1: Engine as a combination of Intake and Exhaust manifold.

2.2.1 Spark-ignition combustion engine

The spark-ignition combustion engine is referred to an engine combined by the 2 following elements:

- ICE[9]
- SI[10]
- Four-stroke engine

2.2.1.1 ICE engine

Describes the engine's combustion. The combustion of the mixture fuel-air occurs in the combustion chamber[11]. The detonation produces high-temperature gases, which with the help of the high-temperature apply forces to components such as pistons and transforms this chemical energy into mechanical energy.

The [Fiat Bravo/a Service Manual Volume], a manual for FIAT engines of the same specifications gives the following formulas for an efficient fuel-air mixture and a good working engine.

- The fuel-air mixture ratio is represented as follows:

  Equation 1

$$\alpha = \frac{quantity\ of\ air\ taken\ by\ engine}{quantity\ of\ fuel\ injected}$$

6 L means litters.
7 Electronic injection.
8 Four-strokes is one full cycle.
9 ICE is the internal engine
10 SI is the spark ignition
11 Combustion chamber is the cylinders of the engine's piston

- Stochiometric ratio is represented as follows:
  Equation 2
  $$\alpha\, st = \frac{theoritical\, quantity\, of\, air}{quantity\, of\, fuel\, injected}$$ [12]

- Mixture concentration is represented as follows :
  Equation 3
  $$\lambda = \frac{quantity\, of\, aire\, taken\, by\, engine}{theoritical\, quantity\, of\, air}$$

2.2.1.2 SI engine

SI is a specification of an internal combustion engine, during which the spark ignites the fuel-air mixture. The last, if between the stroke of intake and exhaust, is compressed in the cylinder by the piston and at a certain moment when:

-
  - the pressure of the mixture is high enough
  - the spark occurs

the detonation happens.

2.2.1.3 Four-stroke engine

Four-cycle[13] is a specification of the internal combustion engine. The piston is attached on the crankshaft, which rotates the base of the piston. As a consequence, this rotational movement is completing four-cycles. One cycle is the extended and full movement of the piston in the cylinder. In the figure 2, there are visible all the four-cycles, which are explained in the following order:

- Intake
  In this stroke, the piston travels from the TDC[14] to BDC[15] position. As the piston travels downwards, it creates a vacuum pressure and gets through the intake valve & the injectors, the fuel-air mixture.

- Compression
  In this stroke, the piston travels from the BDC to TDC, while compressing the fuel-air mixture. For this reason the intake and exhaust valves should be closed. When the piston reaches at the TDC the compressed mixture is ready for the internal combustion.

- Combustion
  This is the ignition stroke, during which:
  i. The piston travels from the TDC to BDC
  ii. The intake and exhaust valves are closed
  iii. The crankshaft completes a full 360 degrees of revolution.
  At the TDC position the spark ignites the combustion, which creates a high-pressure. The last forces the piston to travel downwards, to the BDC position and as a consequence to turn the crankshaft.

- Exhaust
  In this stroke the piston travels from the BDC to TDC position, while the outlet of the fuel-air mixture is occurred. Thus, the exhaust valve should be open.

---

12 Theoritical quantity of air required.
13 Four-cycle is the four-stroke.
14 TDC is the Top Dead Center, which is the maximum extended position that the piston can get in the cylinder.
15 BDC is the Bottom Dead Center, which is the maximum retracted position that the piston can get in the cylinder.

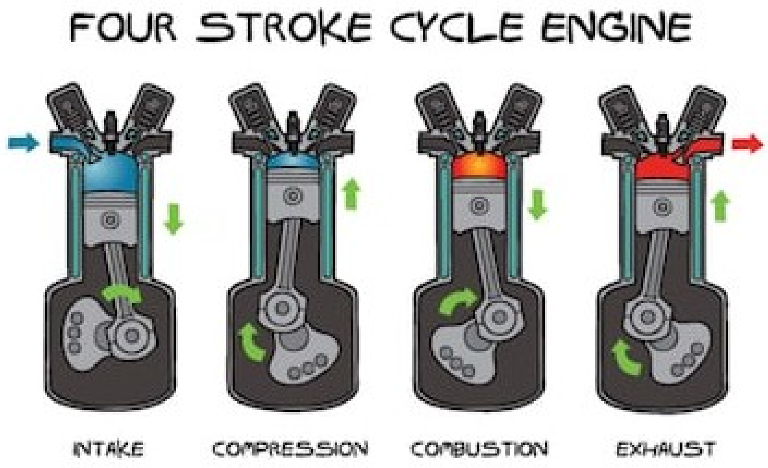


Figure 2: Full four-stroke cycle.

2.2.2 Modeling the engine

In this sub-chapter, the mathematical modeling of a SI, four-cylinder engine will be presented. A well-defined physical principles with empirical relationships, is used to describe the system's dynamic behavior by neglecting unnecessary complexity. It will also be performed as a standalone engine simulation in MATLAB(notation: using matlab's existing example).

2.2.2.1 Mathematical model

In [*Modeling Engine Timing Using Triggered Subsystems*], a Matlab documentation, as referenced by [Crossley and Cook (1991)], is presenting the simulation of a four-cylinder spark ignition internal combustion engine and explains and validates a simulation against to a dynamometer test data. The mathematical model based on Crossley and Cook will be presented as follows:

- Throttle
  It is the first element of modeling. According to Crossley and Cook, it is expressed as the function of the angle of the throttle plate, multiplied by the function of atmospheric and manifold pressure. If the manifold pressure is of low value, then it is neglected.
  Equation 1
  $$\dot{m}_{ai} = f(\theta) \cdot g(P_m) = \text{mass flow rate into manifold (g/s)}$$
  $$f(\theta) = 2.821 - 0.05231 \cdot \theta + 0.10299 \cdot \theta^2 - 0.00063 \cdot \theta^3$$
  $$g(P_m) = 1;\ \text{if } P_m \le P_{amb}/2$$
  $$g(P_m) = \frac{2}{P_{amb}} \sqrt{P_m P_{amb} - P_m^2};\ \text{if } P_{amb}/2 \le P_m \le P_{amb}$$
  $$g(P_m) = -\frac{2}{P_m} \sqrt{P_m P_{amb} - P_{amb}^2};\ \text{if } P_{amb} \le P_m \le 2P_{amb}$$
  $$g(P_m) = -1;\ \text{if } P_m \ge 2P_{amb}$$

- Intake manifold
  The second element of modeling is a differential equation for the manifold pressure. According to Crossley and Cook, it is expressed as the difference in the input and output mass flow rates(notation: net rate of air mass with respect to time), and it is proportional to the time derivative of the manifold pressure(notation: according to the ideal gas law). Exhaust gas recirculation is neglected.

Equation 2

$$\dot{P}_m = \frac{RT}{V_m}(\dot{m}_{ai} - \dot{m}_{ao})$$

- Mass flow rate
  The third element is a function of the maniforld pressure and the engine speed. The equation 3 is derived empirically. The total air charge in each cylinder is obtained by integrating and sampling the mass flow rate, after the end of each intake stroke event and before compression.
  Equation 3

$$\dot{m}_{ao} = -0.366 + 0.08979 \cdot N \cdot P_m - 0.0337 \cdot N \cdot P_m^2 + 0.0001 \cdot N^2 \cdot P_m$$

- Compression stroke
  In the fourth element, each cylinder fires on every consequent crank revolution. Here, an equation for compression stroke is not presented because the combustion takes place in a delay of 180 degrees of a crank rotation, in every intake charge from the consequent end of intake stroke.

- Torque generation and acceleration
  In the fifth element, the torque generated by the engine is presented. The following equation is empirical, and depends:
  i. on the mass of the air charge
  ii. the ratio of air/fuel
  iii. the spark advance
  iv. and the engine speed
  Equation 4

$$Torque_{eng} = -181.3 + 379.36 \cdot m_a + 21.91 \cdot \left(\frac{A}{F}\right) - 0.85 \cdot \left(\frac{A}{F}\right)^2 + 0.26 \cdot \sigma - 0.0028 \cdot \sigma^2 + \\ +0.027 \cdot N - 0.000107 \cdot N^2 + 0.00048 \cdot N \cdot \sigma + 2.55 \cdot \sigma \cdot m_a - 0.05 \cdot \sigma^2 \cdot m_a$$

- Finally, the engine angular acceleration is computed from the equation 5.
  Equation 5

$$J\dot{N} = Torque_{eng} - Torque_{load}$$

2.2.2.2 Simulink model

In [*Modeling Engine Timing Using Triggered Subsystems*], in conjunction with [Ken Butts, Ford Motor Company® (2)], it is presented the simulink model for simulating a four-stroke, SI engine. In the Figure 3, it is given the implementation of a complex nonlinear engine model in Simulink environment.

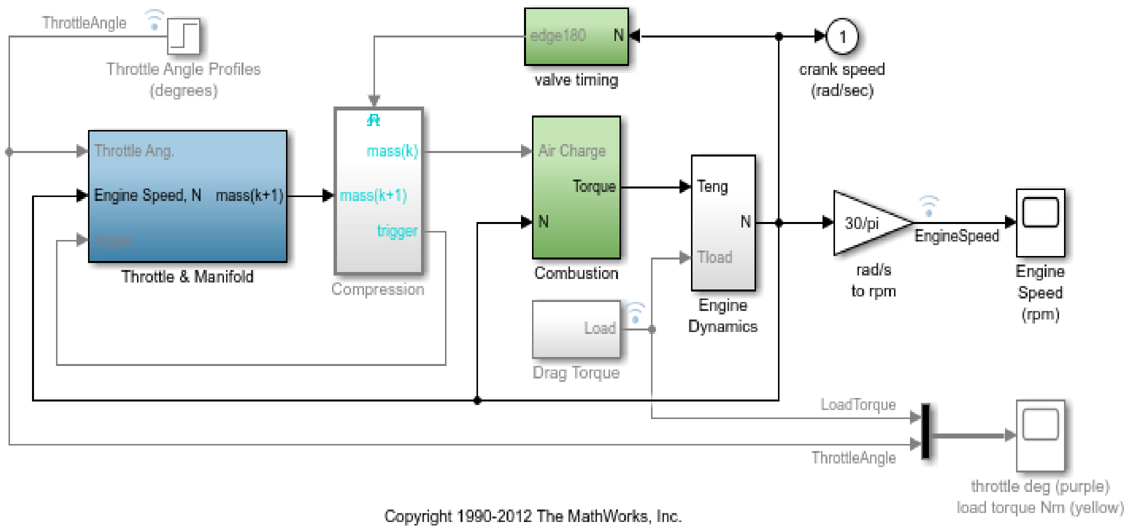


Figure 3: Simulink model of an SI, 4-stroke engine.

The results will be presented as reference for comparison purposes in the "Chaper 10 Results analysis".

2.3 Instrumentation and Actuators

For developing this project, instrumentation and actuators are really important tools. The instrumentation are tools that are needed for the controller of the engine in order to adjust the control signals, when the actuators are the tools that receive the adjusted control signals to provide a certain function. As follows the list of the previous tools, which were used for this project.

The instrumentation list for this project is as follows:

- The knock sensor
- The temperature sensor of the engine
- The Lambda sensor
- The RPM sensor
- The throttle
- The ambient temperature sensor

The actuators list for this project is as follows:

- The injectors
- The canister
- The transformers
- The stepper motor

2.4 Embedded systems

Embedded systems are a combination of hardware and software. They can be:

- Fixed
- programmable
- reprogrammable.

Additionally, they can be used to many different scientific fields. In this project, they are used for simulating and diagnosting different components of the test bench. As follows, the embedded systems that were used for this project:

- Arduino
- Bosch and Multiecuscan diagnostics

2.4.1 Arduino UNO

The Arduino UNO is a board with the following specifications:

- open-source
- micro-controller
- microchip Atmega328P.
-

It is composed by the:

- hardware[16]
- and the software[17].

This specific model of Arduino is chosen because it:

- has low cost
- is practical for only one sensor, due to its size.

In this thesis, it is used to understand the rpm sensor, in order to create, in the future, such a communication to substitute the ECU. In the Figure 4, it is illustrated the hardware part of the Arduino UNO that is used.

Figure 4: Arduino uno.

2.4.2 Bosch and Multiecuscan Diagnostics

The Bosch and Multiecuscan Diagnostics have the same working principles. They are a scan/diagnostic tool for automotive, composed by:

- Hardware, which is an electronic board used for connects vehicle control modules with the computer. The electronic board:

---

16 Hardware means the actual board with the integrated micro-chip.
17 Arduino boards are compatible with many softwares, such as Kinetis, Matlab and Arduino.

i. Bosch,is illustrated in the Figure 5
ii. Multiecuscan, is presented in the Figure 6
iii.

- Software, which is a program in the computer and:
    i. Interfaces
    ii. Diagnoses
    iii. Reprograms

Figure 5: Bosch Diagnostics electronic board.

Figure 6: Multiecuscan Diagnostics electronic board.

2.5 European On Board Diagnostics

On-board diagnostics (OBD), is a system that gives access to check the subsystems of the vehicle. It gets evolved constantly, and nowadays it is common to provide real-time data and information about a detected problem. Physically, it is a hardware interface and more specifically a connector, which is illustrated in the Figure 7.

There are many types of OBD, such as :

- M-OBD
- OBD-I
- OBD-II
- EOBD
- EOBD fault codes
- JOBD

The EOBD that was used in this project is the European on-board Diagnostics (EOBD), which is the system exclusively for Europe and equivalent to OBD-II. Additionally, only four pinouts are used, mainly because there is no vehicle, but only the engine.

Figure 7: EOBD connector.

Chapter 3 Design and Fabrication

In this chapter, the design process and the customization of the components will be demonstrated. By principle, the design but also the selection of the components should be as simple as possible, with the intention of being easily understood by the educational level of the students.

3.1 Engine test stand design

In this analysis, the test stand is designed according to the engine that is going to be used for this project. The specifications of this engine are:

- Brand: FIAT
- Model: Punto
- First FIRE[18]
- Internal combustion
- Spark ignition
- 1.2 i.e.[19]
- Four cylinders
- Four-stroke[20].

In addition, the most important specification is the dimension and the size of the engine, which is 75cm X 80cm. In the figure 8, it is illustrated the first design of the test-stand. The software used for the design is called FreeCAD. This software is :

- free
- easy to learn
- easy to use

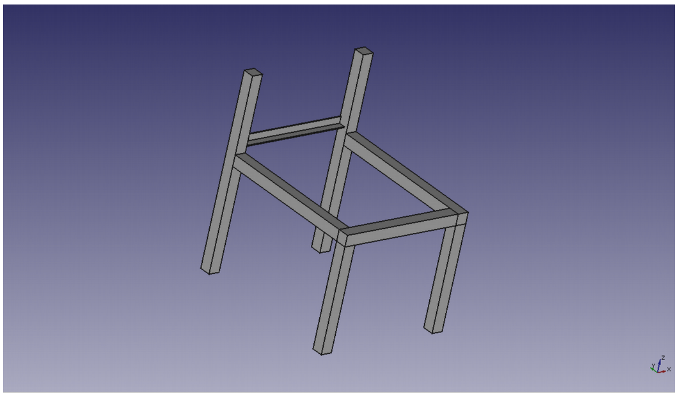


Figure 8: Initial design of the test-stand.

As the project was being developed, some modifications of our initial designs had to be made. These modifications are listed as follows:

- Adjustment & fasten the engine

[18] This specific engine is used for different cars of FIAT, and not only the FIAT Punto.
[19] I.e. stands for 1.2 litters capacity of cylinder electronic injection.
[20] Four-stroke of piston per cylinder.

Placing only the engine is not enough since with the vibrations[21] and fast changeovers the engine will move from its place. This endangers:

i. the destruction of the whole project(notation: all the components can be damaged)
ii. the safety of the members of the team.

Thus, it is understood that the engine should be well fastened. For this reason, certain holes were designed on the test-stand, with the intention of holding strongly the engine. In the figure 9, it is visible the addition of this step.

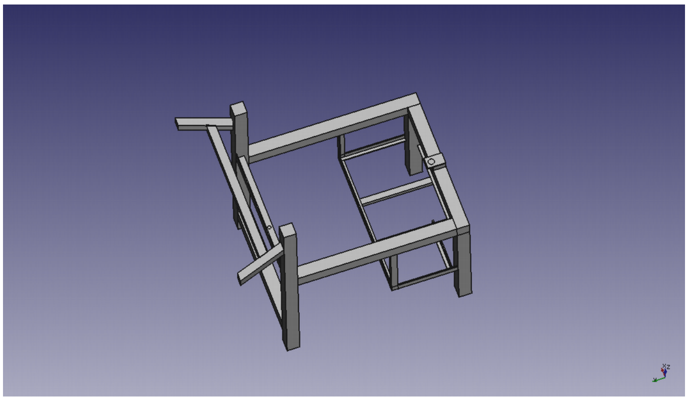


Figure 9: Adjustment & fasten the engine.

- Battery support
  This modification allows the battery to be placed on the test-stand. In this way, the battery is an integrated part of the test-bench and not a distant component. This is considered as an advantage for this project, because there is an immediate access to the battery for emergency situations & safety reasons. In the figure 10, it is obvious the additional tray for the battery support.

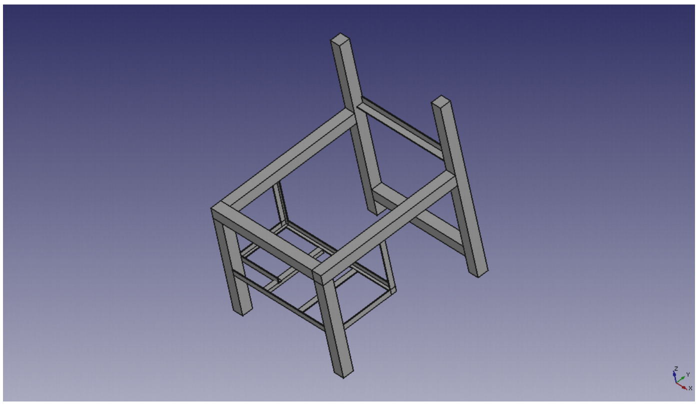


Figure 10: Battery support.

21 Vibration is created in the state of the working engine.

- Fuses & relays table
  For the integration of the fuses & relays, it is important the addition of a bar[22]. On this bar, the components get strongly attached for security reasons. In the figure 11, it is apparent this specific addition.

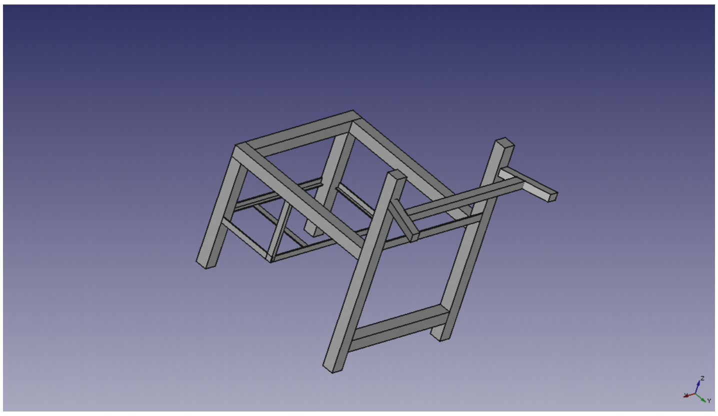


Figure 11: Fuses & relays table.

- Dashboard
  The final addition in our design is the panel[23]for:
  i. start button
  ii. key
  iii. leds
  iv. emergency button
  In the figure 12, it is illustrated the addition of the panel, but also the final form of the whole integrated test-stand.

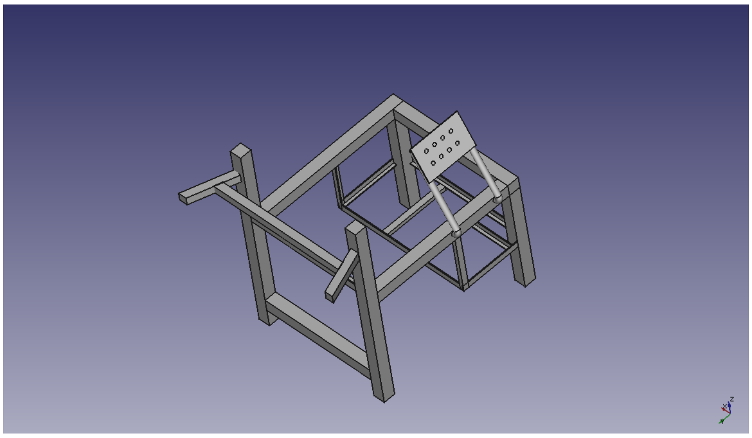


Figure 12: Final form of the test-stand.

After completing the design and before the fabrication of the test stand, one close to our specifications was decided to be used for this project. The material that is made off is steel, which is considered as :

[22] The bar was decided to be called as table.
[23] The panel is the referred Dashboard.

- a good conductor
- having many different ground points

Even though it is heavy and difficult to move, the two previous reasons are enhancing the decision of using it and not buying or constructing a new one.

3.2 Maps

In this sub-chapter, the design and customization of electrical connectors is provided, thus their maps[24]. The maps will be presented in the form of:

- figures, showing the output numbers
- and tables showing the connected elements[25].

3.2.1 Map of EOBD connector

The map of the pinouts of the EOBD connector is described by :

- Pinout number.
  The number of the pinout, which is on the connector and is used in this project.
- Color code of the cable.
  The cable that is used has a specific color to be distinguished.
- The connected element.
  With which component/element it is connected.

The mapping of the connector is presented in the table 1 and illustrated in the Figure 13 The pinouts selected are :

- 4, which is the chassis ground. It includes all the protocols for the electrical circuit.
- 5, which is the signal ground. It includes all the protocols for the electronic circuit.
- 7, where the ISO9141-2 k-Line is included.
- 16, which is the supply of +12V.

Pinout number	Cable color code	Connected element
4	black	minus of the battery (-31)
5	violet	second circuit of the positive of the battery (+15)
7	grey	16 pinout of the ECU
16	red	positive of the battery (+30)

Table 1: map of EOBD pinouts.

24 Maps are the association of the pinouts of the electrical connector, with the appropriate components.
25 In association with the pinout number.

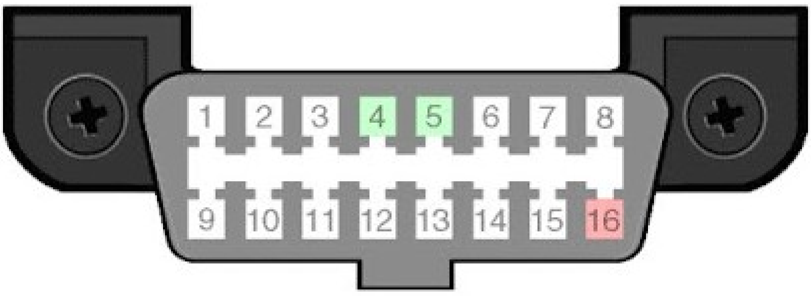


Figure13: EOBD pinouts.

3.2.2 Map of relays

The relays[26] used for this project are three in total, and are implemented in the two following circuits:

- Sensors/ECU, which is illustrated in the figure 14
- Dashboard
  The dashboard is illustrated in the figure 15 The design is on the free software Qelectrotech. The pre-design of the electrical circuit of the dashboard was developped with the help of the lab supervisor. The reason was to decide the place of the relay in this circuit.

As follows, their implementation and mapping:

- K3
  This is the principle 30A relay of the main circuit sensors/ECU. In the figure 16 it is illustrated the internal connection. In the figure 17 it is presented the pinout map. Finally in the table 2, is apparent the connection with the rest of the circuit.

[26] Relay is a switch that can be electrically operated.

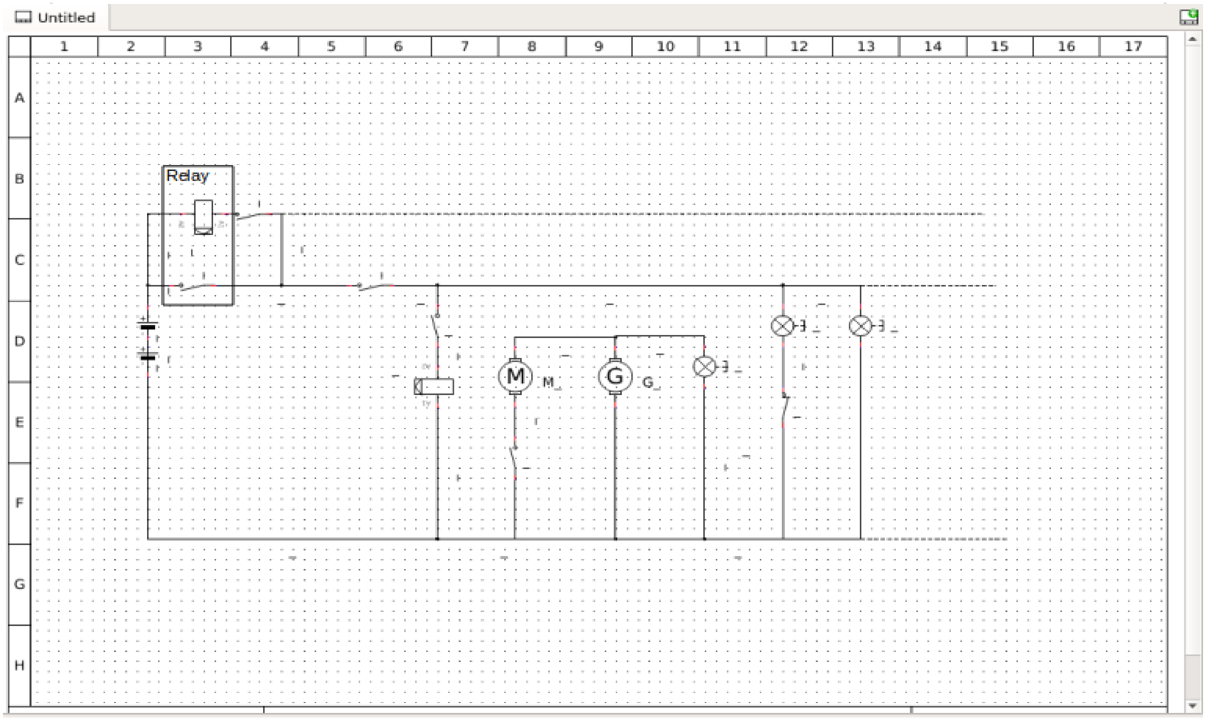


Figure 15: Dashboard circuit.

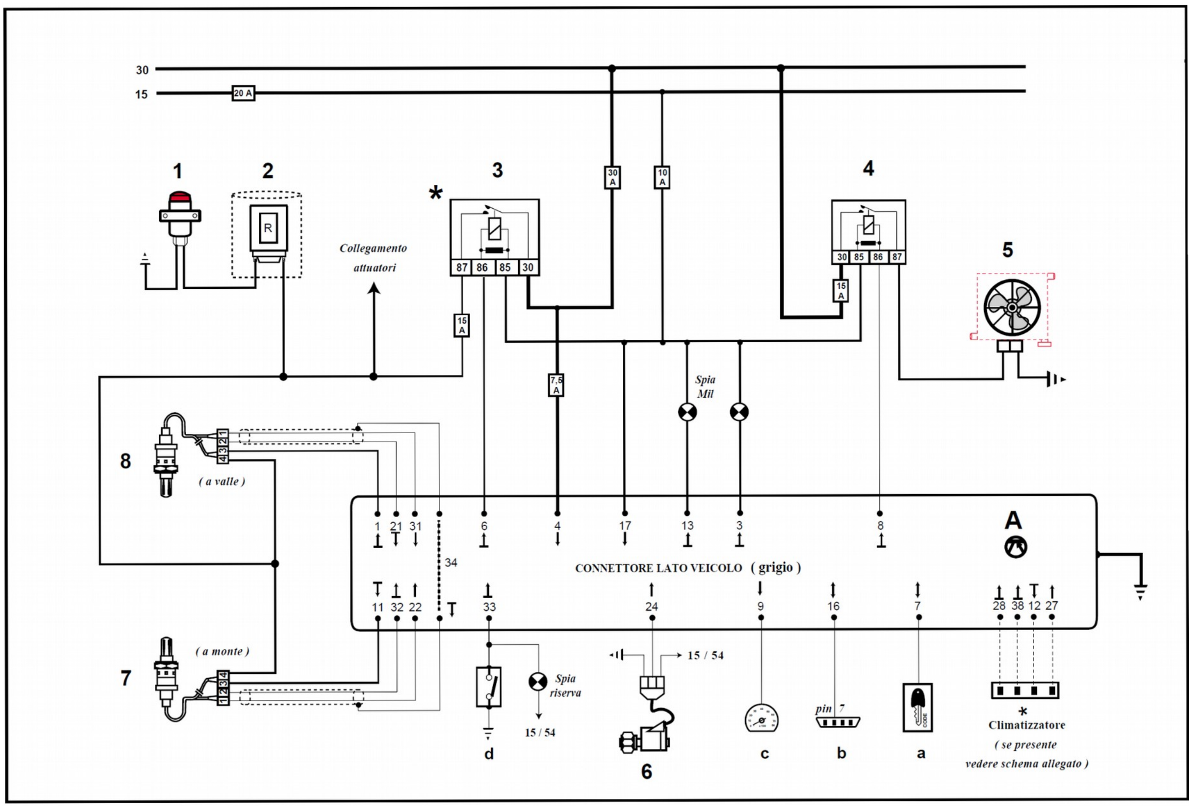


Figure 14: circuit sensor/ECU.

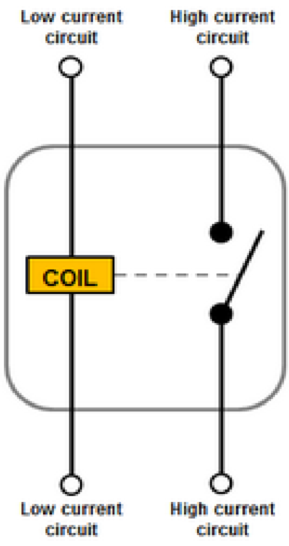


Figure 16: Internal connection of relay.

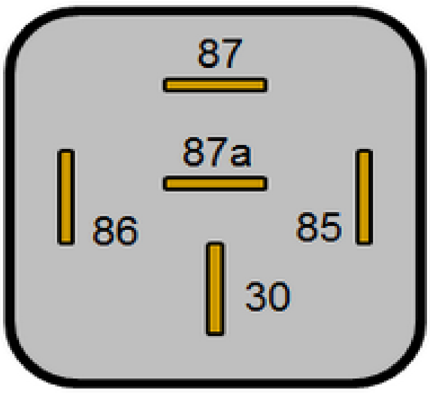


Figure 17: Pinout of relay.

Pinout number	Connected element
87	Via a 15Afuse, to : i. main circuit actuators/ECU ii. fuel pump iii. lambda sensor
87a	None
86	ECU
85	Secondary relay
30	Battery

Table 2: The connection with the rest of the circuit.

- K4
  This is the secondary 20A relay of the main circuit sensors/ECU. The internal connection is the same as the K3 relay, But the pinouts are only 4, which are illustrated in the figure 18 The table 3 provides the connection with the rest of the circuit.

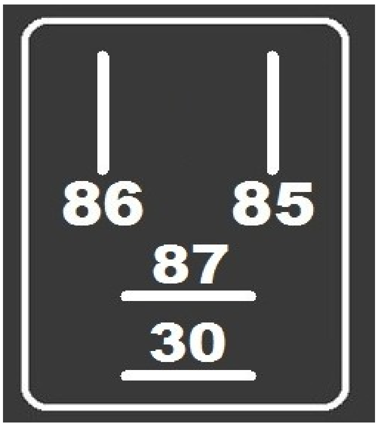


Figure 18: Relay with 4 pins.

Pinouts	Connected element
30	Via a fuse, to the battery
85	Priciple relay K3
86	ECU
87	Fan

Table 3: Connection with the rest of the circuit.

- K1
  This 20A relay is used for the electrical circuit of the dashboard. The internal connection is the same as the two previous relays. The pin sketch is the same as the K4 relay. In the table 4, it is provided the connection with the rest of the circuit.

Pinouts	Connected element
30	Positive pin of battery
85 - 86	Parallel with emergency button
87	Positive pin of the key

Table 4: Connection with the rest of the circuit.

3.2.3 Map of fuses

The fuses[27] used for this project are the following:

- F16[28], 10A
- F33, 30A
- F20, 15A
- F18, 7.5A
- F44, 30A
- F22, 15A
- F11, 15A

They have been mapped in a two shelve board of fuses. The board is customized to have a fuse of two cables of the same size. The cables are distinguished by the size as follows:

- T, which means small
- M, which means medium
- B, which means big.

In the tables 5a & 5b, it is presented the association of:

- size of cable
- position
- fuse

The two empty slots are being customized with the intention of attaching the fuses board to the test stand.

The position of the fuses in the main circuits of:

- sensors/ECU
- actuators/ECU,

are illustrated in the Figure 20 & Figure 19.

		F44	F22		F11
M		B	B		M
M		B	B		M

Table 5a: mapping fuses F44, F22, F11.

27 Fuse is an electrical component, which provides safety of overcurrent.
28 F refers to Fuse.

F16		F33		F20	F18
T	T	B	M	B	T
T	T	B	M	B	T

Table 5b: Mapping fuses F16, F33, F20, F18.

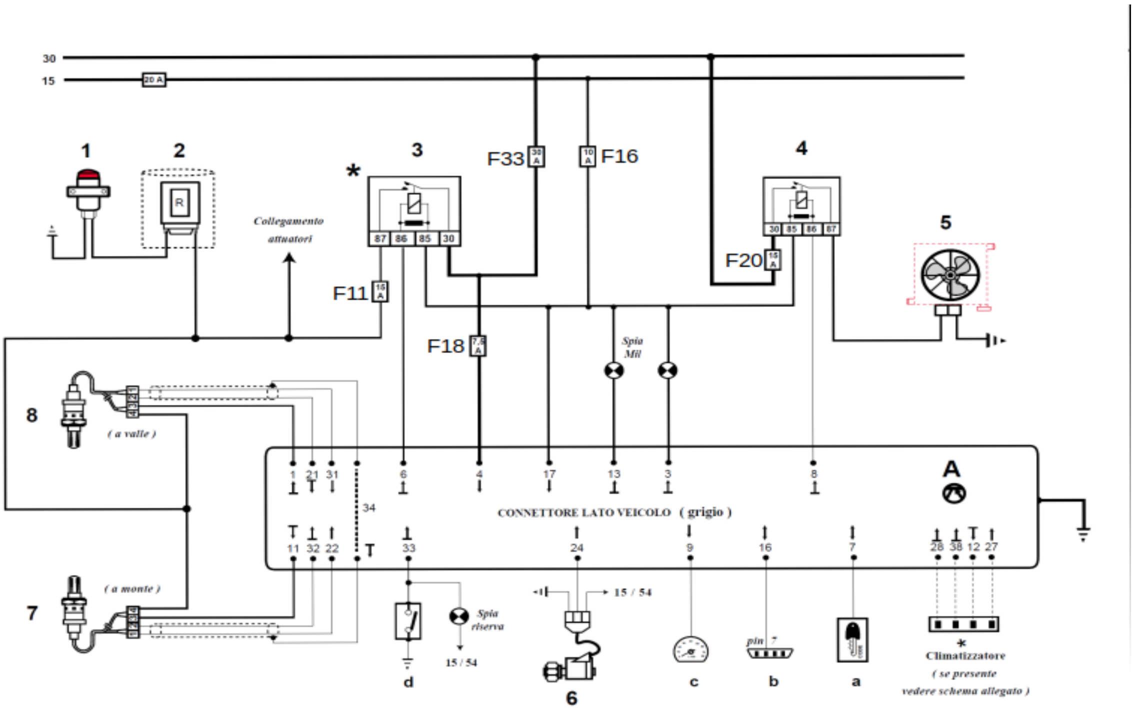


Figure 19: Fuses in circuit sensors/ECU.

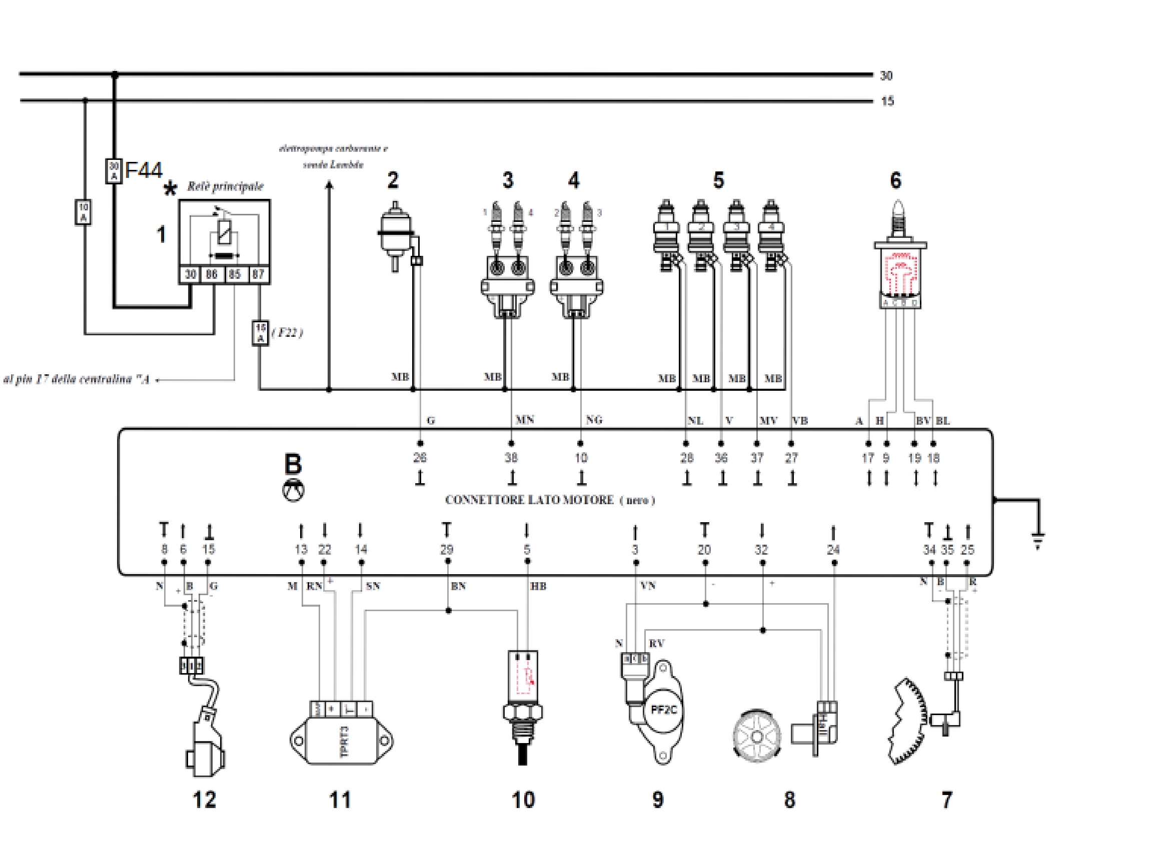


Figure 20: Fuses in circuit actuators/ECU.

3.2.4 Map of ECU connectors

In this sub-chapter, it is provided the map of the connector A for the main circuit sensors/ECU. The ECU that is used in this project specifically is the IAW59F. In the figure 21, it is illustrated the ECU connectors platform. The right part is dedicated to the connector B and the left part to he connector A.

Since the connector A that was available, did not have all the pinouts that were needed for the connectivity of the sensors, it was necessary to create another connector.

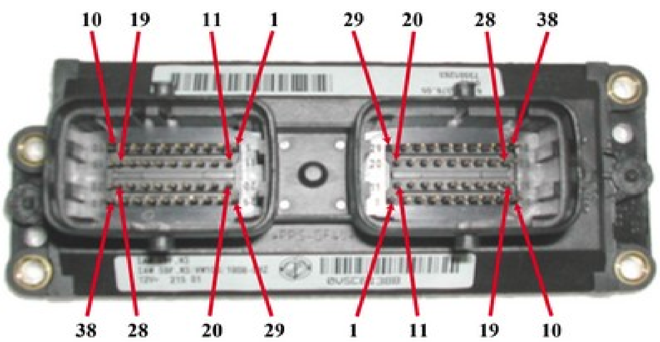


Figure 21: ECU connectors A & B.

In the figure 22, is illustrated the connector A. In the table 6, it is given the pinouts of each connector, with their connected elements of the circuits.

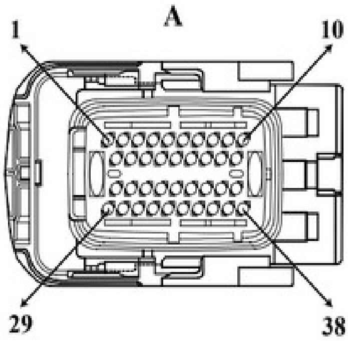


Figure 22: Connector A.

Pinout	Connected element
4	Positive of battery
6	K3 main relay
17	Common mode between K3 & K4
13	Led for common mode between K3 & K4
3	Second led for common mode between K3 & K4
8	Secondary relay K4
16	EOBD connector
33	Fuel level selector
34, 22, 32, 11	Lamda sensor

Table 6: Pinouts & conneted elements of connector A.

Chapter 4 Didactical test-bench integration

This chapter will be provide the integration of the test-bench, which means that it will be explained how every component got added on the whole system. This procedure will be analyzed in steps, starting from the basis: positioning of the test-stand, until the very advanced verification of the good working condition of the test-bench. The reason is that, if the verification shows that there is a problem in a component, then the steps of the integration will may have to be repeated.

4.1 Positioning of the test-stand

For the first step, after finishing the design with all the specifications satisfying the requirements of the test-bench, it was decided to use an existing test-stand. The needed to alternate it, based on the design and choosing the location of its position in the lab, was emerged. The location was chosen according to the following specifications:

- a big enough open space
- no obstacles in the near environment
- no easily accessed by students and other people not authorized
- appropriate safety measurements, such as fire extinguishers
- no flammable and/or explosive materials in the near environment.

After placing the test-stand at the appropriate place, it was easy to move on to the next step.

4.2 Adjustment of the engine

For the second step, it was really important to unmount the whole mechanical parts of the engine and make sure that they are:

- clean
- and in a good condition.

Both of these characteristics can indicate the future working condition of the engine. For instance:

- leakage problem between mechanical components, due to deformed components
- stuck components because of remaining dirt.

After making sure of the good state of the engine, it was necessary to place it carefully in the test-stand. Additionally, it was really important to make sure that the engine is really well mounted on the test-stand and with the vibrations of the testing will not get unmounted.
Considering that this step is successfully over, it is possible to continue to the next step.

4.3 Placement of instrumentation and sensors

For this step, all the instrumentation[29] & sensors, are tested to verify:

- their working condition
- and that they are suitable for this engine, according to the reference signal[30].

[29] Instrumentation is the actuators
[30] More in chapter 5.

After the verification, the instrumentation and the sensors are integrated , according to the two main circuits[31].

4.4 Placement of the ECU

In this step, the ECU is placed in front of the intake valve case[32]. Consequently, it gets connected with the instrumentation and sensors, according to the two main circuits[33]. In the figure 24, there are presented all the components that are connected with ECU. The following table 7 contains the elements that are implemented in this test-bench and are listed according to their number in the same figure:

Number	Element
1	ECU
2	oil pressure sensor
4	idle step motor
5	injectors
6	canister
7	EOBD connector
8	sparks
9	transformers
10	high temperature warning
11	ECU warning
13	temperature sensor
14	high pressure
15	position potentiometer
16	knock sensor
17	rpm sensor
18	key
19	lambda sensor
20	fuel pump
21	relays
27	low level fuel
28	Battery

31 These circuits are the basis of this project.
32 The valve lets the air inside the engine and according to the quantity of the air, it controls the power output.
33 Sensors/ECU & actuators/ECU.

Table 7: The association of the numbers with the elements that are illustrated in the Figure 23.

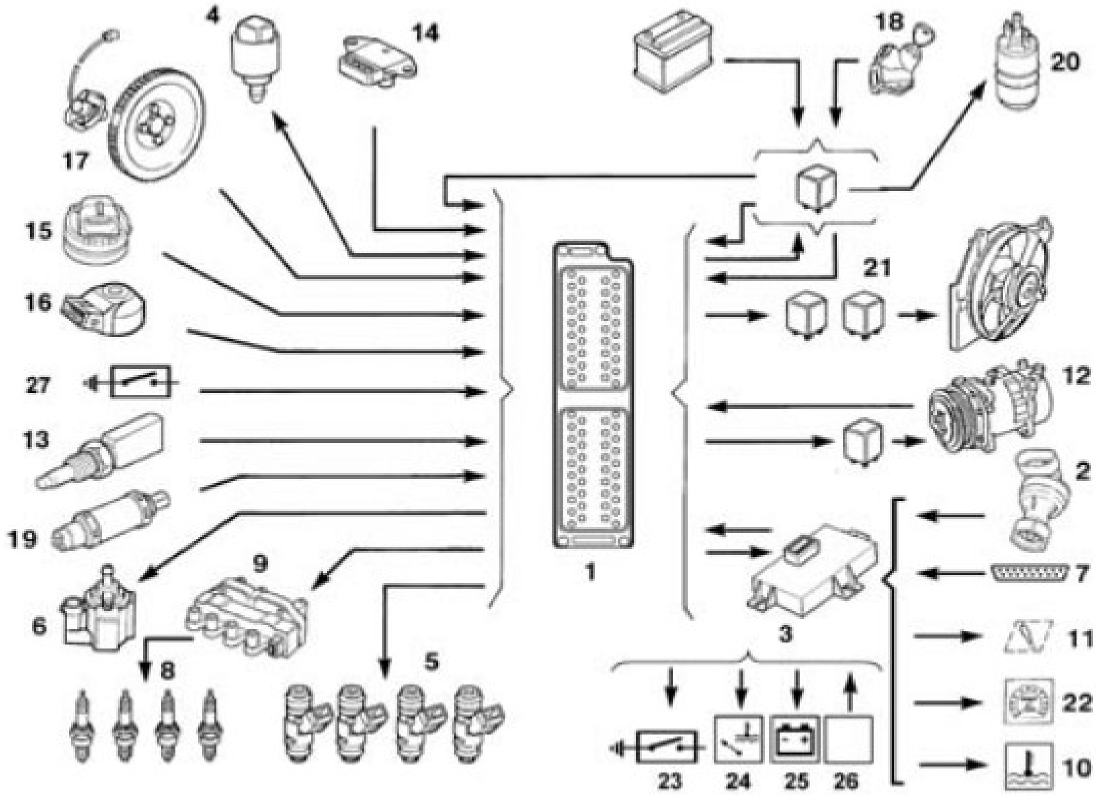


Figure 23: Components connected to ECU.

As a final part of this step, is the connection with the:

- battery
- Bosch diagnostics[34],

to verify that the components are functioning.

4.5 Installation of the dashboard

After deciding which elements need to be added and placed at the dashboard, the first design of the electrical circuit is created and modified it accordingly to get its final version. Consequently, the dashboard gets attached in the test-bench. Once more, the battery gets connected, for verifying the good working condition of the dashboard. After the comletion of this step, the next step is starting.

4.6 Additioning of the fuses and relays

In this step, the addition of the fuses and relays takes place. According to:

- the maps
- dedicated place of the test-stand,

[34] Software & Hardware

the fuses and relays get integrated in the test-bench. As follows, the battery gets connected to verify the correct connectivity. After disconnecting the battery, the verification of their working condition takes place, with the appropriate instruments. After satisfying this step, it is easy to go to the final step.

4.7 Conclusion

The final test-bench integrated is illustrated in the figure 24.

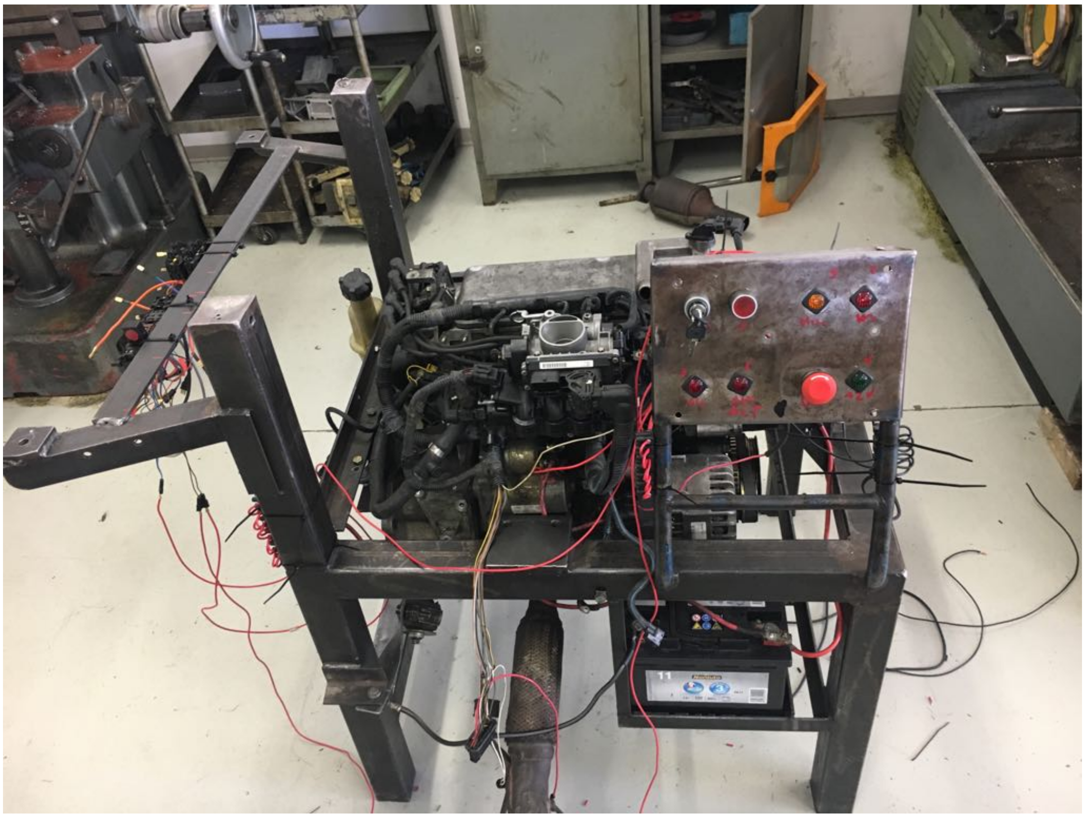


Figure 24: Test-bench fully integrated.

Chapter 5 Instrumentation and actuators

In this chapter, there are presented the instrumentation and actuators, which are used in this specific project. The main components are provided, except the:

- TDC sensor
  This sensor was not available, so it was decided to:
  i. proceed without it
  ii. and measure it in another way, which will be analyzed in the Chapter 8: Testing procedures
- Reference signals, which will be analyzed in the Chapter 7: Calibration.

5.1 Instrumentation

In this sub-chapter, there are provided all the sensors that were used for this project. The instrumentation, is the way that the ECU receives and reads signals to control efficiently the actuators. They are presented as follows:

- functionality
- position in the test-bench
- connector layout
- testing for verifying the working condition and the compatibility with the engine that is used in this project.

5.1.1 Knock sensor

Knock for a four-cycle engine, is when the detonation of the combustion does not occur at the right moment. This indicates a faulty condition.

Technically, the knock sensor could be described as a microphone, in which there are:

- a crystal
- an internal resistance
- supporting contacts.

It is tuned in frequency of the detonation[35] of the engine.

The detonation creates vibrations, which are detected by the crystal inside the knock sensor. Since sensor and detonation are tuned in the same frequency, then the crystal vibrates as well. This vibration creates the output voltage of this sensor. The ECU uses this signal to:

- adjust the optimal moment of detonation
- detect a faulty working condition[36].

Physically, the sensor is well mounted in front of the cylinders, so that it will immediately sense the detonations.
Electrically & electronically, the sensor is connected to the ECU in the main circuit of actuators/ECU.

In the figure 25, it is illustrated the knock sensor, which is used for this project. In the figure 26, it is given the connector layout of the sensor.

[35] Detonation is also called pinging.
[36] By comparing with the look up tables, which are included in the ECU.


Figure 25: Knock sensor.

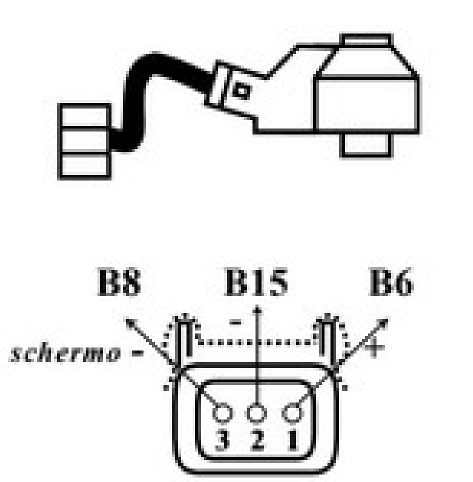


Figure 26: Connector layout of the knock sensor.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance
- and compare it with the reference values, which are provided in the figure 27.

For this test, two sensors were used. In the table 8, it is given the:

- reference value
- the measured values of first and second sensors.

Components	**Resistance values**
Reference	530 ÷ 580 Ω
1st	50 KΩ
2nd	500 KΩ

Table 8: Internal resistance of knock sensors.

As it is apparent, the two sensors do not respect the reference range. For this step, the first sensor is chosen since it has the closest value.

Misure di resistenza su Attuatori			
Ohm	Stop	**Singolo elettroiniettore**	**14 ÷ 16 Ω**
Ohm	Stop	**Sensore di giri / P.M.S.** *(term 1 - 2)*	**1100 ÷ 1400 Ω**
Ohm	Stop	**Riscaldamento sonda Lambda** *(term 3 - 4)*	**3 Ω**
Ohm	Stop	**Elettrovalvola vapori benzina**	**35 ÷ 58 Ω**
Ohm	Stop	**Sensore di battito**	**530 ÷ 580 Ω**
Ohm	Stop	**Attuatore del minimo** *(term A - D)* *(term B - C)*	**50 ÷ 60 Ω**
Ohm	Stop	**Potenziometro acceleratore** *(term a - b)*	**1200 ÷ 1250 Ω**
		(term a - c)	**0 → 1200 Ω**
Ohm	Stop	**Sensori temperatura** *(motore)* *(aria) (nel sensore pressione assoluta)* *0 °C*	**9.5 KΩ**
		10 °C	**3.8 KΩ**
		20° C	**2.5 KΩ**
		60° C	**500 Ω**
		80° C	**300 Ω**
		90° C	**200 Ω**
Ohm	Stop	**Bobina A.T.** *(primario)*	**0,5 ÷ 0,65 Ω**
		(secondario)	**6850 ÷ 7850 Ω**

Figure 27: Reference table of internal resistances.

5.1.2 Temperature sensor of the engine

The temperature sensor[37] is sensing the temperature level of the engine. Technically, this specific sensor is consisted by:

- brass case
- and internal resistance, which is a potentiometer.

This potentiometer is actually an NTC thermistor[38], which decreases the value of the electrical resistance, as the temperature of the engine increases.

The circuit designed between the ECU and the sensor is a voltage divider. Thus, the voltage changes through the resistance of:

- the ECU
- and the sensor.

[37] The temperature sensor is also called coolant temperature sensor.
[38] NTC is Negative Temperature Coefficient.

As a consequence, the ECU detects every change based on the changes of the voltage.

Physically, the sensor is tightened[39] at the thermostat case, which is:

- in the intake manifold
- and as close as possible to the engine.

Electrically & electronically, it is connected to the ECU through the circuit of actuators/ECU.

In the figure 28, it is illustrated the engine temperature sensor. And in the figure 29, it is provided the connector layout.

Figure 28: Engine temperature sensor.

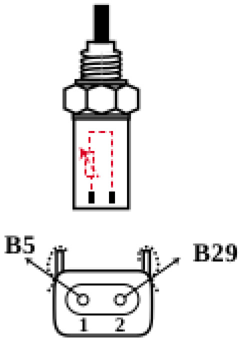


Figure 29: Connector layout of the temperature sensor.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

39 Tightened with a torque of 2.4 daNm.

As a result, in the table 9, it is presented the following resistance values:

- reference
- measured,

for the same ambient temperature[40]. Obviously, the sensor satisfies the reference value for this specific engine.

Temperature	Reference Value	Measured value
19 °C	2.9 KΩ	2.7 KΩ

Table 9: Internal resistance of temperature sensor.

5.1.3 Lambda sensor

Generally, the lambda sensor measures the exhaust gas oxygen content. The sensor consists of:

- a ceramic case
- the previous enclosed in a protective pipe
- both of the first placed in a metal case
- an internal resistance.

The lambda is the output signal that goes to ECU in order to adjust the fuel-air mixture to keep as stable as possible the stochiometric level. The ideal mixture should be equal to 1. According to the Equation 3, Chapter 2,

$$\lambda = \frac{Intake\ air\ quantity}{theoritical\ quantity\ of\ needed\ air}$$

there are the following situations:

- λ=1 ideal mixture
- λ<=1 rich mixture
- λ>=1 lean mixture

The ratio should be 14.8 parts of air in order to burn 1 part of fuel[41].

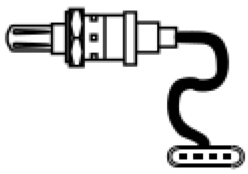
To start the sensor working, the temperature should exceed the 300°C. Only then the ceramic material starts conducting oxygen ions. The internal part detects the atmospheric air, when external part[42] contacts the exhaust gas. Both of these parts verify the level of the oxygen, and if these two levels are different, then a voltage is created. The ECU detects this voltage as follows:

- if the voltage is less than 200mV, then the mixture is lean, and as a consequence the ECU increases the amount of fuel injected
- if the voltage is greater than 800mV, then the mixture is rich, and as a result the ECU decreases the amount of fuel injected.

The sensor is tightened at the exhaust manifold[43], before the catalyst. Electrically and electronically the sensor is connected with the ECU at the main circuit sensors/ECU. In the figure 30, it is illustrated the lambda sensor. And in the figure 31, it is presented the connector layout of the lambda sensor.

40 The sensor is considered to be in the ambient temperature.
41 The ratio should be 14.8:1.
42 The external part is the ceramic part.
43 Tightened with torque 3.5 ÷ 4.5 daNm.

Figure 30: Lambda sensor.



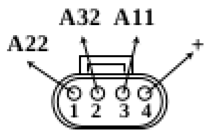


Figure 31: Connector layout of the lambda sensor.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

In the table 10, it is given the following resistance values:

- reference
- measured.

It is apparent that the value of the internal resistance is close enough.

Reference Value	Measured Value
3 Ω	4.1 Ω

Table 10: Internal resistance of lambda sensor.

5.1.4 Rpm sensor

The rpm[44] sensor is a magnetic inductive sensor, which synchronizes:

- the crankshaft though the phonic wheel
- and the ECU.

It consists of:

- a permanent magnet
- an electrical coil
- an internal resistance

The permanent magnet creates a fluctuated[45] magnetic flux[46], which applies electromotive force on the electrical coil. Through the terminals of the coil, the output signal is provided. The output signal is a fluctuated voltage, in which the amplitude is dependent on the gap between the sensor and the phonic wheel.

When the rpm sensor is reading the teeth of the phonic wheel:

- The tooth represents the positive part
- The gap represents the negative part

of the output signal.

The phonic wheel is a wheel in a toothed form. Usually attached to the rod of a motor. In this engine though, it is attached to the crankshaft. And it is made of soft iron. The phonic wheel has 60 teeth:

- 58 teeth
- with two missing teeth[47].

For tuning the phonic wheel with the ECU, it is important to get synchronized with the first tooth right after the gap of the two missing ones. The gap between:

- the phonic wheel
- and the rpm sensor

should satisfy the gap range of 0.5 ÷ 1.5mm.

Physically, the sensor is positioned to face perpendicularly with its magnetic part, the phonic wheel. In the figure 32, it is illustrated:

- the rpm sensor
- and the phonic wheel

In the table 11, it is provided the association of the main parts and the numbers of the figure 32.

Referenced number	Main parts
1	Rpm sensor
4	Connector
7	Teethed phonic wheel

Table 11: Association of main parts & numbers of the figure 32.

44 Rpm stands for revolutions per minute.
45 Fluctuation is a vibration, which shifts back and forth uncertainly.
46 Due to the teeth detection.
47 The two missing teeth are for tuning purposes.

Electrically & electronically, the sensor is connected to the ECU in the main circuit of actuators/ECU.

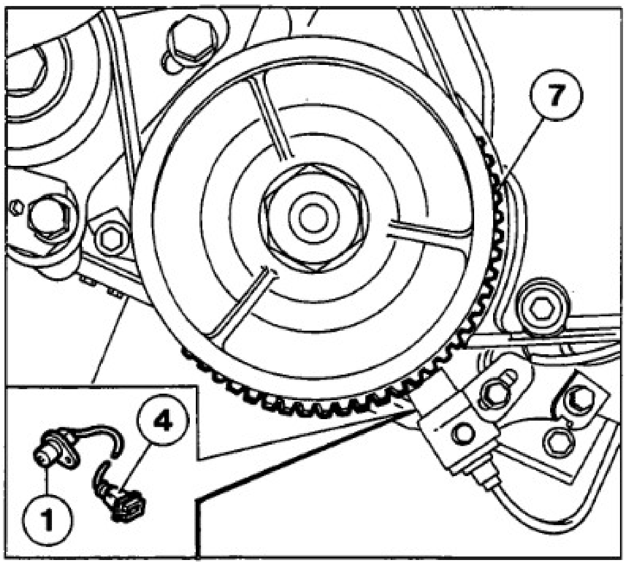


Figure 32: Positioning of the rpm sensor.

In the figure 33 & 34, it is presented:

- the connector layout
- and the rpm sensor.

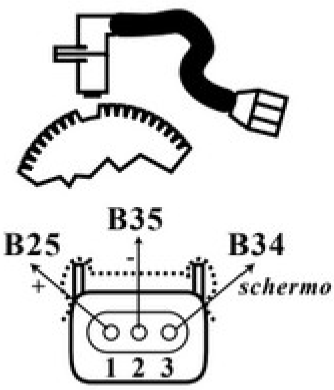


Figure 33: Connector layout of the rpm sensor.

Figure 34: The rpm sensor.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

As a consequence, in the table 12 is given the internal resistance values:

- reference
- measured.

Reference range	Measured
1.100 ÷ 1.400 Ω	927 Ω

Table 12: Internal resistance of the rpm sensor.

It is obvious that the measured values of the internal resistance is lower and outside of the reference range.

5.1.5 Throttle

The throttle sensor[48] is a type of a potentiometer, which is managed by the throttle valve spindle. The throttle consists of the:

- potentiometer
- throttle valve spindle
- internal resistance
- connector for the ECU.

Via the corresponding connector, the ECU:

- supplies with voltage the sensor
- receives an output voltage signal from the sensor.

This output voltage represents the throttle opening:

48 The throttle sensor refers to the throtle valve position sensor.

- from the idle[49]
- to the full opening

position of the plate, which gets rotated by the spindle. As a result, the ECU receives this output signal and accordingly adjusts the issued signals for controlling the actuators.

The effective electrical angle is in the range of: 2° ÷ 90°, for the explanation of the physical opening of the throttle valve. And the mechanical angle is in the range of: 4° ÷ 105°, for the representation in the plot of the figure 35.

Physically, the sensor is fastened in the intake manifold, since it is the main controlling valve for the intake air. Electrically & electronically, the sensor is placed in the main circuit of the actuators/ECU.

In the figure 36, it is given the throttle valve position sensor. The connector is a three-pin with capital ABC letters[50] socket. And in the figure 37, it is provided the connector layout of the throttle sensor.

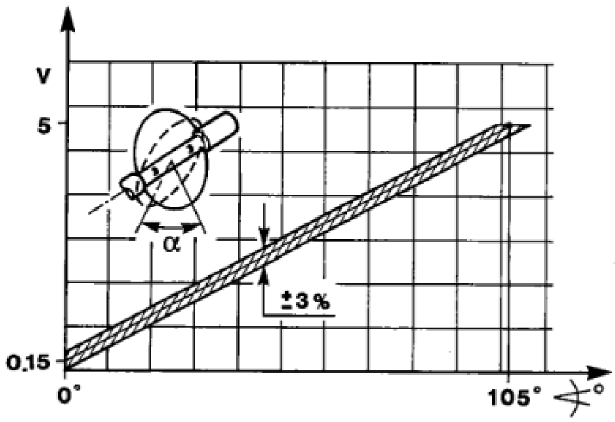


Figure 35: Plot of the throttle valve.

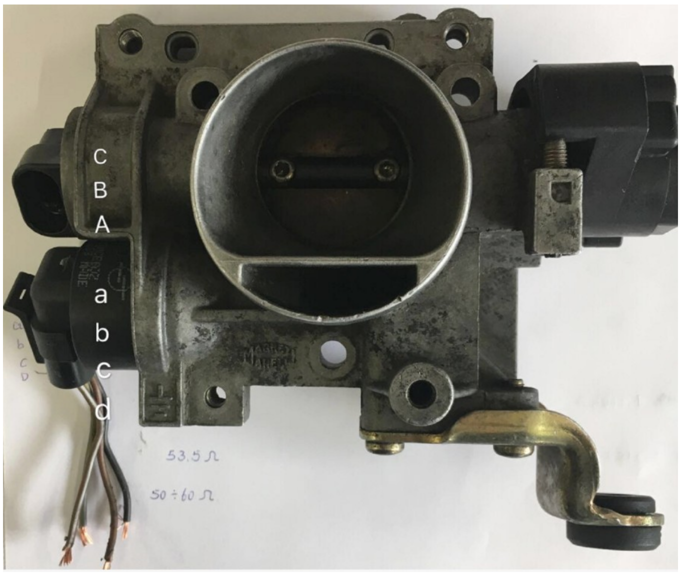


Figure 36: Throttle valve position sensor.

49 Idle position is when the throttle valve is fully closed.
50 The ABC letters are associated/referred to each pin.

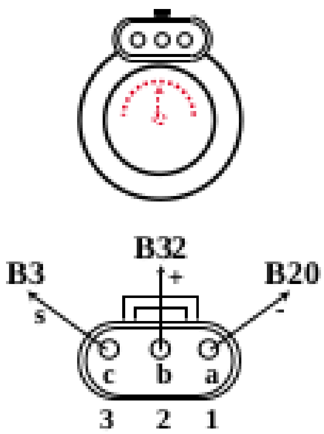


Figure 37: Connector layout of the throttle sensor.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

As a consequence, in the table 13 is provided the:

- internal[51]
- and potentiometer resistance,

according to the testing angles of the throttle valve.

Testing angle	Pinouts	Reference range	Measured value
-	a-b	1.200 ÷ 1250 Ω	1.167 Ω
0°	a-c	0 ÷ 1.200 Ω	1.961 Ω
45°	a-c	0 ÷ 1.200 Ω	3.418 Ω
90°	a-c	0 ÷ 1.200 Ω	2.738 Ω

Table 13: Internal resistance & potentiometer of the throttle sensor.

5.1.6 Ambient temperature sensor

The ambient temperature sensor functions as:

- a reference and comparison signal
- and an adjustment and control signal,

for the ECU.

The sensor is composed by:

- the absolute pressure sensor
- and the ambient temperature sensor.

[51] Reference & measured value.

As a result, the ambient temperature sensor consists of an internal resistance, which works as a potentiometer. The potentiometer is an NTC thermistor, which decreases the value of the electrical resistance, as the ambient temperature increases. The sensor follows the same working condition as the engine temperature sensor.

Physically, the sensor is fastened in the intake manifold. Electrically & electronically, it is connected to the ECU through The the main circuit of actuators/ECU. In the figure 38, it is illustrated the ambient temperature sensor. And in the figure 39, it is provided the connector layout. The pin-out association is given in the table 14.

Pin-out	**Functionality**
a-b	Power supply
a-c	Absolute pressure sensor
a-t°	Ambient temperature sensor

Table 14: Pin-out association.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

Figure 38: Ambient temperature sensor.

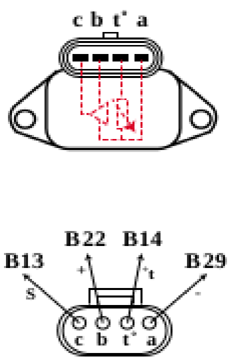


Figure 39: Connector layout of the ambient temperature sensor.

As a consequence, in the table 15 is presented the internal resistance values as follows:

- reference
- measured

for the same ambient temperature. Apparently, the internal resistance of the sensor satisfies the reference value.

Ambient temperature	Reference value	Measured value
19°	2.9 KΩ	2.5 KΩ

Table 15: Internal resistance of the ambient temperature sensor.

5.2 Actuators

In this sub-chapter, there are provided all the actuators that were used for this project. The actuators receive the signals issued by the ECU, thus the ECU works as a controller. They are presented in the same way as the instrumentation, thus:

- functionality
- position in the test-bench
- connector layout
- testing for verifying the working condition and the compatibility with the engine that is used in the project.

5.2.1 Injectors

The injectors are actuators, which are used to supply with fuel the cylinders. In this project, there are used four injectors[52].

The injector functions as a top-feed electrical valve. It follows the sequence of the cylinder intake stages[53], as they are all synchronized by the ECU. It consists of:

- the part of the valve, which functions as a normally closed valve to avoid excess fuel in the cylinder & not in the right stroke.
- and the part of the injector, which supply the cylinder with fuel.

Physically, the injectors are fastened in the appropriate seats in the intake manifold, and more specifically on the fuel supply manifold. Electrically & electronically, the actuators are connected to the ECU through the main circuit of actuators/ECU.

In the figure:

- 40, it is presented the fuel supply manifold.
- 41, there are illustrated the four injectors.
- 42, it is provided the connector layout.

[52] It is referred to one injector per cylinder.
[53] It refers to the cylinder in the stroke of the intake, as seen in chapter 2.

Figure 40: Fuel supply manifold.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

As a consequence, in the table 16 is provided the internal resistance values as follows:
- reference
- measured, for each injector.

Figure 41: The four injectors.

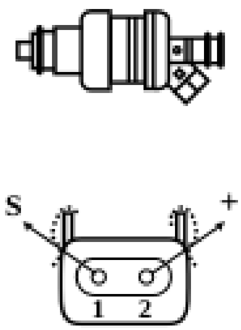


Figure 42: Connector layout of the injectors.

Injector	Reference value	Measured value
1st	14 ÷ 16 Ω	15.1 Ω
2nd	14 ÷ 16 Ω	14.9 Ω
3rd	14 ÷ 16 Ω	15 Ω
4th	14 ÷ 16 Ω	15 Ω

Table 16: Internal resistance of the injectors.

5.2.2 Canister

The canister is the fuel vapor cut-off valve and it consists of:

- valve
- pipes, which connect:
  - i. the intake manifold
  - ii. active carbon filter.

This valve controls the quantity of fuel vapors that leave the active carbon filter and get directed to the intake manifold. It is a normally closed valve to prevent the fuel vapors enriching the mixture excessively.
This actuator operates if:

- the engine is warm.
- the ECU sends a square wave signal to control the opening of the valve in order to enrich the fuel-air mixture when needed.

And cannot operate if:

- the throttle is in idle positioned.
- the rpm<1.500.
- the intake manifold pressure is less than a limit value.

Physically, it is located in the intake manifold. Electrically and electronically, it is connected to the ECU through the main circuit actuators/ECU. In the figure:

- 43, it is illustrated the canister
- 44, it is provided the connector layout.

Figure 43: Canister.

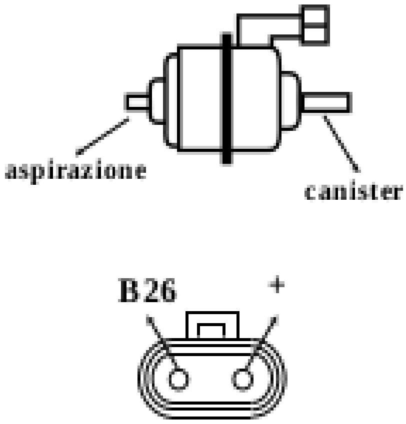


Figure 44: Connector layout of the canister.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

As a result, in the table 17 is provided the internal resistance values as follows:

- reference
- measured.

It is obvious that the internal resistance satisfies the reference value range.

Reference value	Measured value
35 ÷ 58 Ω	37 Ω

Table 17: Internal resistance of the canister.

5.2.3 Transformers

The transformer is an actuator, which enables the sparks. In this project, there are two transformers used for the four sparks.

This actuator consists of:

- primary
- secondary

winding, with a narrow physical gap between them.

The primary winding is connected to the ECU, while the secondary winding:

- a
- b,

are connected to the four sparks, which are associated to the cylinders. In the table 18, it is given the association between sparks and secondary windings.

Secondary winding	Spark - cylinder
a	1 - 4
b	2 - 3

Table 18: Association between secondary windings and sparks/cylinders.

The ECU gives the signal to the transfomers , which enable the sparks. Since one transformer enables two sparks at the same time, it is evident that one of the two sparks is getting lost[54].

Physically, the actuator is positioned near the camshaft cover. Electrically & electronically, it is connected to the ECU through the main circuit actuators/ECU. In the figure 45, there are presented the two transformers. And in the figure 46, it is provided the connectors layout.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

As a consequence, in the table 19 is provided the internal resistance values as follows:

- reference
- measured,

for each transformer.

[54] One spark finds the combustion stroke of one cylinder, when the other spark finds the intake stroke of the other cylinder.

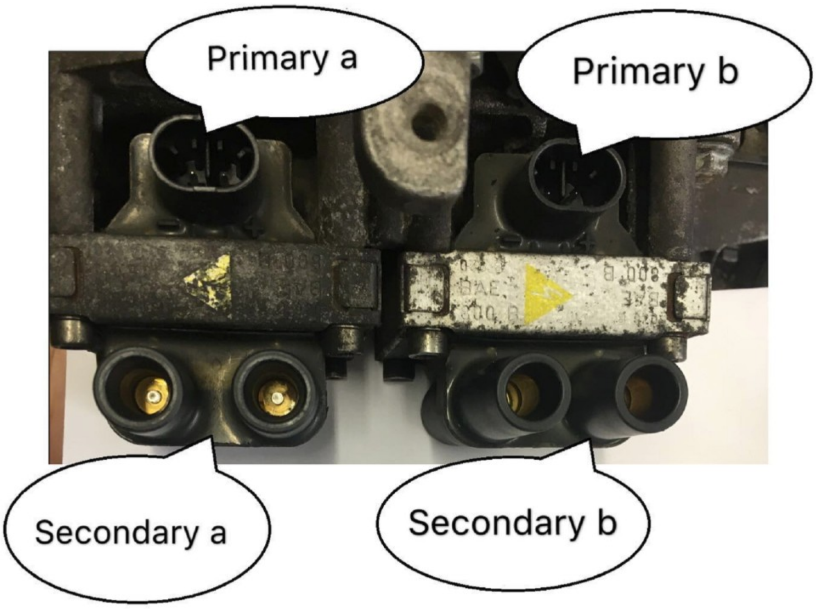


Figure 45: Transformers.

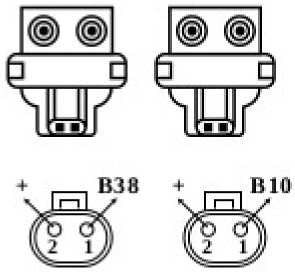


Figure 46: Connectors layout of the transformers.

Transformers	Reference value	Measured value
Primary winding «a»	0.5 ÷ 0.65 Ω	0.6 Ω
Secondary winding «a»	6.850 ÷ 7.850 Ω	7.270 Ω
Primary winding «b»	0.5 ÷ 0.65 Ω	0.6 Ω
Secondary winding «b»	6.850 ÷ 7.850 Ω	7.150 Ω

Table 19: Internal resistance for the transformers.

5.2.4 Stepper motor

Stepper motor is the idle speed control actuator.

This actuator is composed by:

- the motor
- and a linearly moving piston, by a rotational screw motion.

The signals from the sensors are sent to the ECU, which processes them and according to these signals it sends controlling signals to the idle speed cotrol actuator. As a consequence, this actuator regulates the air volume, which passes via the throttle, to control the idle speed of the engine in the approximately zero degree position of the plate of the throttle.

Physically, the actuator is placed in the throttle valve case, right after the throttle with the intention of regulating immediately the volume of air passing through. Electrically & electronically, the stepper motor is connected to the ECU through the main circuit of the actuators/ECU. In the two following figures 47 & 48, it is presented the stepper motor and the connector with the numbered pinouts.

Figure 47: Stepper motor.

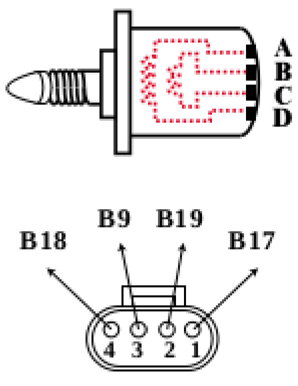


Figure 48: Connector with pinouts.

For the verification of the working condition and the compatibility with this specific engine, it is needed to:

- measure the internal resistance only after having measured the ambient temperature
- and compare it with the reference values on the same temperature, which is provided in the figure 27.

In the table 20, it is provided the measured value as well as the range of the reference value. From the measurement, it is obvious that the value of the internal resistance of the actuator is stausfying the reference range.

Stepper motor pinouts	Reference value	Measured value
A - D B - C	50 ÷ 60 Ω	53,5 Ω 53,4 Ω

Table 20: Internal resistance of stepper motor.

Chapter 6 Control and data acquisition strategy

In this chapter, the control and data acquisition will be presented and analyzed. The control refers to the controller[55] of the engine, which is the ECU[56], in the presented project. The data acquisition[57] is performed by two diagnostics tools[58], which will be explained analytically. A comparison between these softwares will be provided at the end of this chapter, only for explanation purposes.

6.1 Controller ECU

The controller used for this project, is the ECU with the code of IAW59f. For this analysis the controller is assumed as a gray box[59], since it has the following features:

- Based on the schematics provided by the lab supervisor, the parts that the ECU controls can be easily seen as provided in the figures 19 & 20[60].

- Once again, based on the creation of the connector for the main circuit sensors/ECU, it is apparent the understanding of the needs of:
  i. the ECU
  ii. and the system.
  In the figure 22 & table 6[61] it is presented the map of this connector.

- The two diagnosis softwares, provide a full image of the working condition of the ECU, which receives signals from the sensors as a feedback and adjusts the signals for the actuators. In the figure:
  i. 49 is illustrated an example of the Bosch diagnostics.
     The figure of this diagnosis is not from the engine of this project, but it is an example only for presenting purposes. The reason is that the Bosch Diagnostics does not have the possibility to get a file with the diagnosis.

  ii. 50 is presented an example of the Multiecuscan diagnostics.
     In this figure, it is provided an example from the specific engine of this project, showing a problem of the ECU. It belongs to the phase of the testing procedure when the components had been positioned and tested to see if they are recognized by the ECU.

- The code written in the ECU is unknown. It is written in different programming languages, for different parts that it controls. The ECU also includes lookup tables and stand-alone simulink models. For the:
  i. code
  ii. stand-alone simulinks
  iii. lookup tables,
  it is not easily possible to access and modify them.

Thus, it is evident that even though it is understood what is the concept of ECU, it is not easy to be modified in its internal system.

55 The controller is the unit that manages the operation of a system.
56 ECU stands for the Engine Control Unit.
57 Data acquisition is the process of collecting, storing and presenting information data.
58 These diagnostic tools are embedded systems.
59 Gray box is a system, for which its working condition is partially known & understood.
60 In Chapter 3.
61 In Chapter 3.

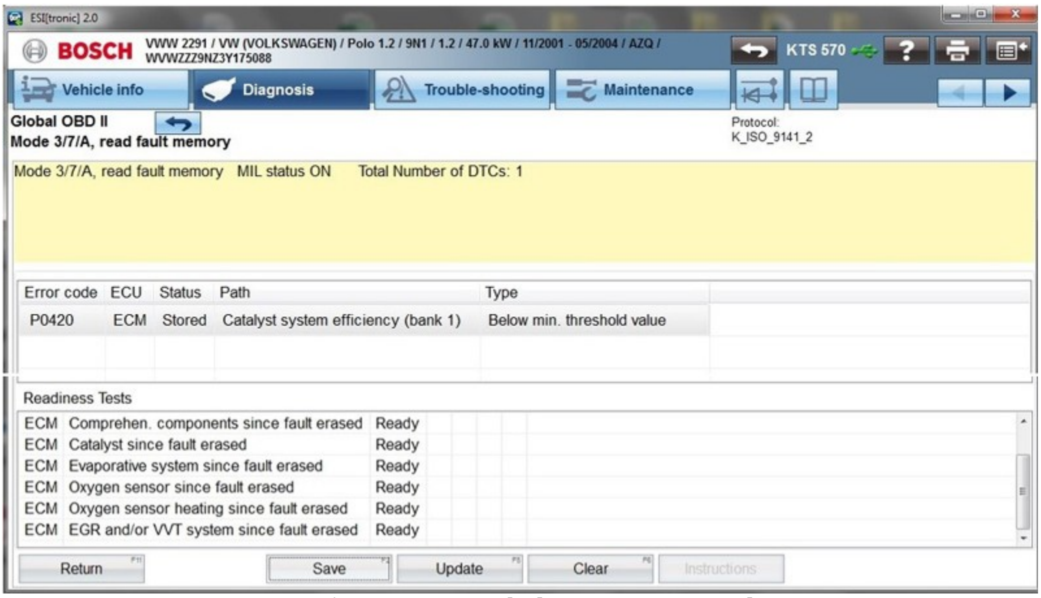


Figure 49: Bosch diagnostics example.

```
ECU ISO Code: 0D 07 13 80 7C
02/05/2018 10:23:54
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
--------------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

READING ERROR CODES:
1: U1600 - Electronic key
ERROR DETAILS:
Electronic key code: Not received
Engine temperature: 24 °C
Intake pressure: 0 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.

Anomaly concerning the electronic key ECU immobilizer function. The electronic key ECU has not received the key code or the code is not
included among the memorized ones.
Possible causes:
- Key non original or broken
- Ignition coil antenna disconnected or damaged
- Electronic key ECU supply
The reason for this fault is that ECU has received invalid signal from the sensor. The fault is present now. Take appropriate action to
fix this sensor fault. Dashboard warning light was not activated for this fault.
2: P0230 - Fuel pump relay
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 24 °C
Engine speed: 0 rpm
Intake pressure: 0 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.
```

Figure 50: Multiecuscan diagnostics example.

6.2 Bosch Diagnostics

The Bosch Diagnostics is a tool, from which the following performances are provided:

- Professional and DIY[62] diagnostics, which give information about the working condition of the engine, as well as the health state of all the components.
- Crash data retrieval[63].

It is an embedded system, which means that it is connected a specific programmed microcontroller [64] to the EOBD[65] for collecting the data of each component that ECU controls. The software remotely receives the data and analyses them. In this way, Bosch Diagnostics provides with accurate information for the components that need to be repaired. The data can be stored as graphs, which is not considered as a flexible way, since it is important to analyze the raw data.

In addition, the graphs that are illustrated in the figures 51, 52 & 53, present some examples of a good working condition engine. By :

- changing the throttle pedal
- and selecting the parameters, which need to be analyzed,

it is visible that Bosch's Diagnostics graphical representations do not give enough and analytical information, since it has an important delay on the change of the throttle. Which means, that if the throttle doesn't stay stable for some seconds then the representation is wrong and the data not accurate.

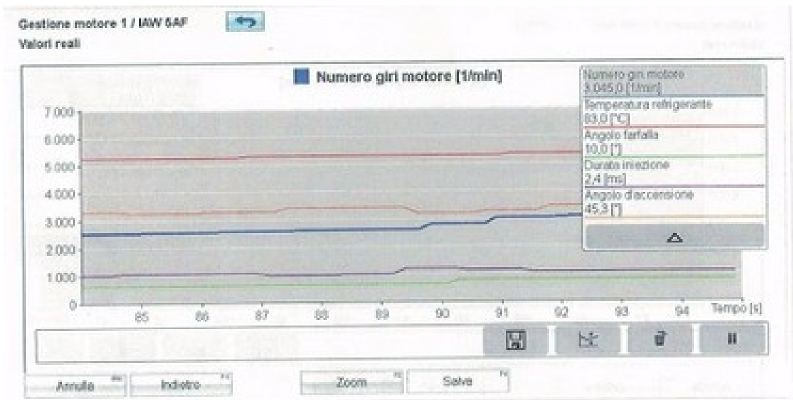


Figure 51: Bosch diagnostics first graph.

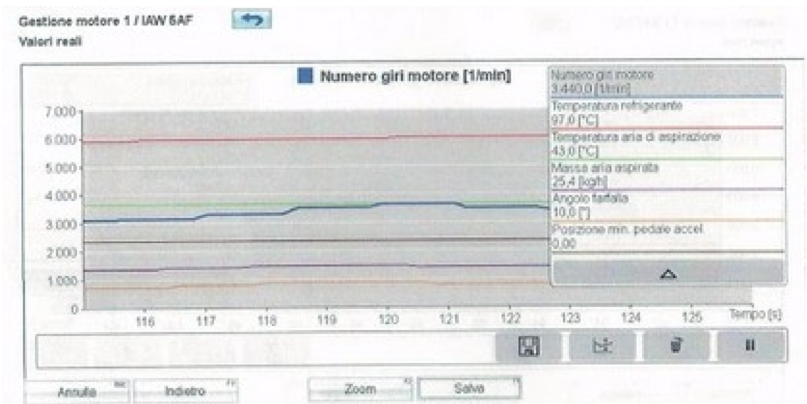


Figure 52: Bosch diagnostics second graph.

62 DIY stands for do it yourself.
63 It retrieves the data after a crash has happened.
64 Electronic board.
65 EOBD stands for European on-board diagnostics.

As a consequence, in the first experimental states, Bosch diagnostics was used for showing the exact faulty components in a step by step analysis process.

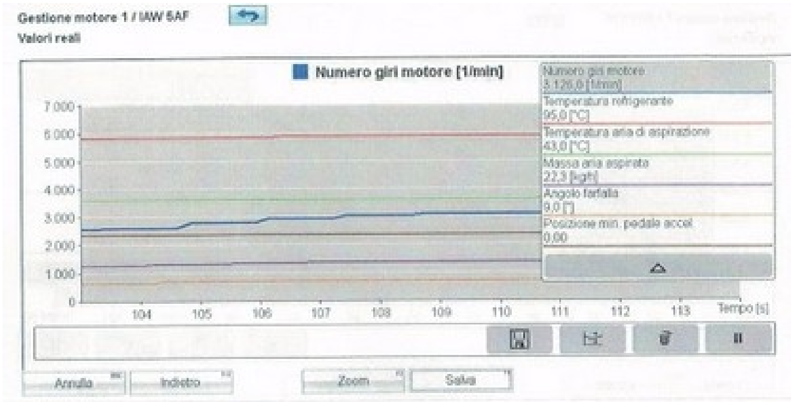


Figure 53: Bosch diagnostics third graph.

6.3 Multiecuscan Diagnostics

The Multiecuscan Diagnostics is one more diagnostics tool, which again gives the information of the state of the components that ECU controls.

It is once more an embedded system, since the programmed microcontroller board is connected:

- physically to the EOBD of the testbench
- remotely to the running in the computer software.

The data stored, are in the form of graphs but also in the form of numerical data. This software gives the stored data in a file with the extension of .csv, which can be:

- seen in excel
- easily manipulated by matlab.

As a consequence, it was used during the data storing process.

6.4 Bosch and Multiecuscan Diagnostics

The comparison between the two above diagnostic methods, shows that both of them give the same important information about the state of the components but the representation of the data is different.
More specifically, it is provided:

- the information about the health of the components
- data stored as graphs

On the other hand :

- Bosch diagnostics is more analytical in the diagnosis process
- Multiecuscan diagnostics is proved to be more convenient for data storage.

As follows, this leads to the decision of using a combination of both of them :

- in the first experimental phase, the Bosch diagnostics was used to show analytically the faulty components, which are preventing the start of the engine

- while in the second phase, the Multiecuscan is used to show the components, which need adjusting and to store the data in a manipulable file.

6.5 Conclusions

In this chapter, there are available information about the:

- testbench controller ECU
- two diagnostics embedded systems and arduino, which are used as data acquisition methods.

The ECU is described as a gray box since the information are partially available for its internal system. The diagnostics that are used in this project, is a combination of two programs in two different experimental phases. Finally the arduino is giving the chance of preparing the concept of future work, and it will be explained and analyzed in the chapter 11.

Chapter 7 Calibration

The components[66] that are implemented in this project, do not need calibration, because they are bought ready for:

- implemntation[67]
- and use.

As a consequence, it will be provided the range of output voltage signal for each component. In addition, this chapter is devided in two parts. The first part is providing the output ranges and the second part, the ECU's:

- synchronization
- and self-adaptation.

7.1 Range of output signal

In this sub-chapter, it is provided the range of the output voltage signal. For each component, the information needed is obtained by plots and tables.

- **Knock sensor**
  This sensor is tuned with the frequency of the detonation in the cylinder. When the combustion takes place, the output signal:
  i. starts fractuating
  ii. reaches the maximum value peak to peak
  iii. slowly it loses its fractuation
  iv. reaches almost steady state condition.
  The figure 54, presents the reference signal of the output voltage according to the previous explaination. Moreover, the range of the output voltage is 0V ÷ 5V.

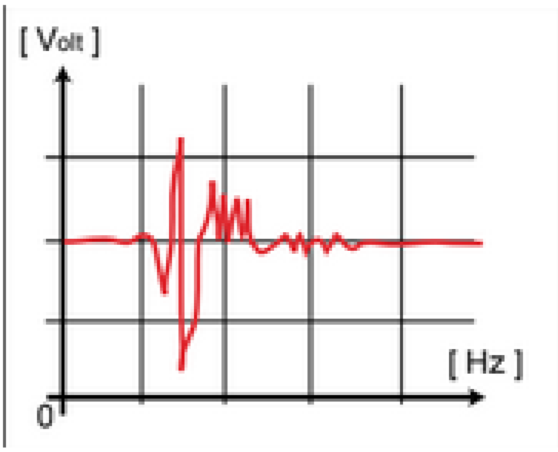


Figure 54: Reference output signal of the knock sensor.

- **Temperature sensor of the engine**
  This sensor is axplained in the following steps:
  i. starts from the highest amplitude of the output voltage
  ii. the temperature of the engine increases
  iii. and the output voltage decreases.

[66] Instrumentation and actuators.
[67] Placement & replacement.

The figure 55, illustrates the signal of the reference output voltage according to the previous analysis. In addition, the range of the output voltage is 0V ÷ 5V.

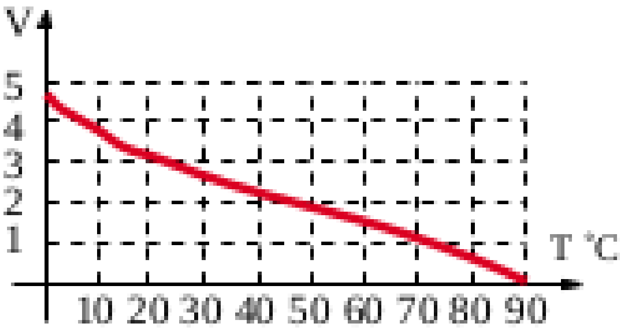


Figure 55: Reference signal of the temperature sensor of the engine.

- **Lambda sensor**
  In order for ECU to receive the signal of this sensor, a frequency signal form should be used. The important information can be obtained by the:
  i. maximum
  ii. and minimum amplitude of the curve[68].
  These amplitude points give the information of the:
  i. rich
  ii. lean mixture,
  of the combination of air and fuel, which is its method to regulate and the signal to the ECU to adjust accordingly the mixture.
  The figure 56 presents the reference output voltage signal according to the previous explaination. Additionally, the range of the output is 0.1V ÷ 0.9V.

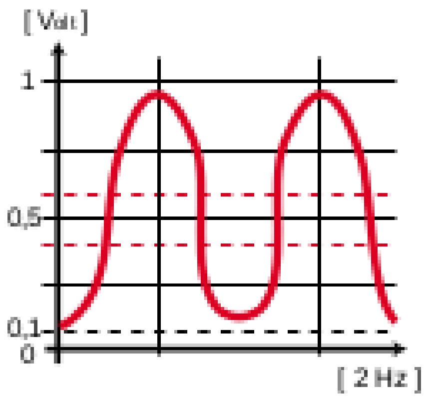


Figure 56: Reference signal of the lambda sensor.

There are three important zones, which indicate the texture of the mixture of air and fuel. They are presented in the table 21, as explained in the following columns:
i. the zone / range
ii. The explanation

[68] The curve of the reference signal

iii. The action to be done

Zone / Range	Explanation	Action
0.1V ÷ 0.4V	Rich (notation: on fuel)	Decrease fuel
0.4V ÷ 0.7V	Optimal	Do not change anything
0.7V ÷ 0.9V	Lean	Increase fuel

Table 21: Zones / Ranges of the voltage output signal.

- **Rpm sensor**
  This sensor is based on magnetic function. It is placed in front of the phonic wheel of the engine. The phonic wheel has sixty teeth, and an empty slot, which coresponds to two teeth[69]. The important information may be obtained by the following:
  i. The output signal is fractuating in a defined threshold
  ii. When the RPM sensor passes by the two missing teeth, the amplitude of the fractuating curve increases.
  In the figure 57, it is provided the reference output voltage signal according to the previous analysis.

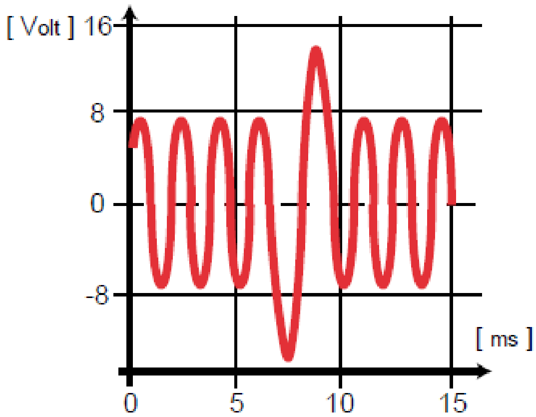


Figure 57: Reference output voltage signal of RPM sensor.

There are two important zones, which indicate the position of the missing teeth, thus one full round of the phonic wheel. They are given in the table 22. The columns are displayed as follows:

i. zone
ii. explanation

Zone / Range	**Explanation**
-7.9 ÷ 7.9	Detecting tooth
-15.8 ÷ 15.8	Detecting the two missing teeth

Table 22: Zones of the voltage output signal.

69 Two missing teeth

- **Throttle**
  For this sensor, there is no reference output voltage signal. The table 23 gives the voltage outputs for the:
  i. rest
  ii. and the fully open
  position of the plate of the throttle. In addition, it associates with the corresponding opening in degrees.

Output voltage	Position	Opening in degrees
0.8V	Rest	0.5°
4.8V	Fully open	88°

Table 23: Output voltage range of the Throttle.

- **Ambient temperature sensor**
  This sensor follows the same logic as the temperature sensor of the engine, which is explained in the following steps:
  i. starts from the greatest output voltage value
  ii. the temperature increases
  iii. then the output voltage decreases
  The figure 58 illustrates the reference output voltage signal of this specific sensor, according to the previous analysis. Consequently, the range of the output is 0V ÷ 5V.

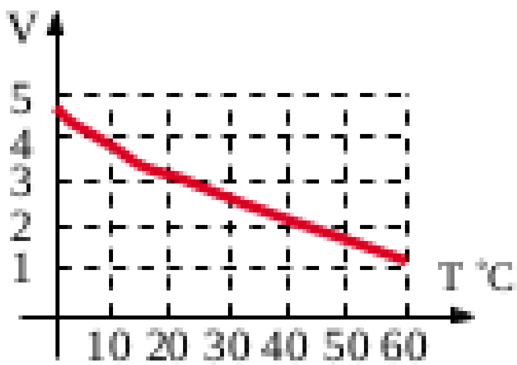


Figure 58: Reference output voltage of the ambient temperature sensor.

- **Injectors**
  There are four injectors in this project. The injector is an actuator, which is associated to one and only cylinder.
  In the figure 59, it is presented the reference output voltage signal of all the four injectors. In the table 24, it is provided the sequence of each injector actuation.

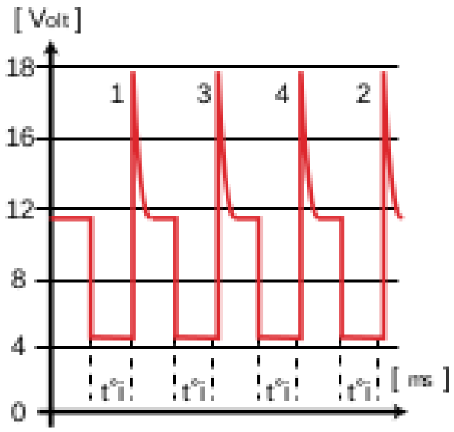


Figure 59: Reference output voltage signal of the full cycle of injections actuation.

Sequence of injector's actuation	Injector's number	Cylinder's number
1st phase	1st injector	1st cylinder
2nd phase	3rd injector	3rd cylinder
3rd phase	4th injector	4th cylinder
4th phase	2nd injector	2nd cylinder

Table 24: Sequence of injector actuation.

- **Canister**
  The ECU controls this actuator, by issuing frequency signals. For the actuator's good working condition, the rpm of the motor should be in the range 2000 ÷ 2500.
  The figure 60 provides the reference output voltage signal, with range 0.5V ÷ 11.9V.

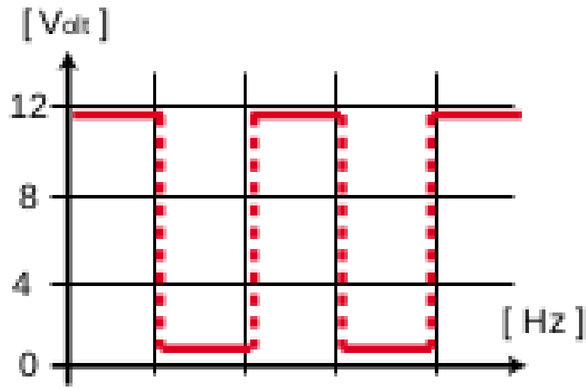


Figure 60: Reference voltage output signal of the canister.

- **Transformers**
  This actuator provides an analog voltage signal to the sparks, for spark-ignition. Thus this output signal should be:
  i. similar to the one of the knock sensor
  ii. but with less duration of the fractuation
  The figure 61 presents:
    i. the reference output voltage signal of this actuator
    i. with range -5V ÷ 5V.

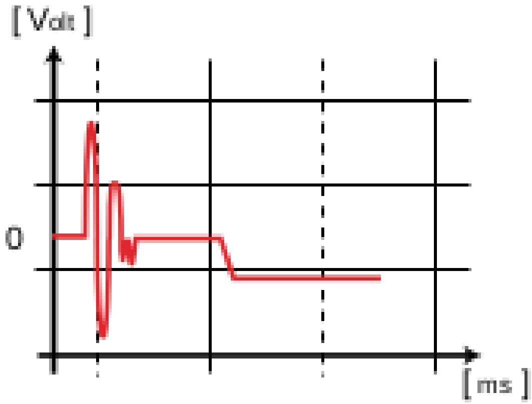


Figure 61: Reference output voltage signal of the transformers.

- **Stepper motor**
  This actuator provides the digital output voltage of the idle control speed. A frequency signal issued by ECU, controls this actuator.
  The figure 62 illustrates the:
  i. reference output voltage signal
  i. range of output voltage, which is -12V ÷ 12V.

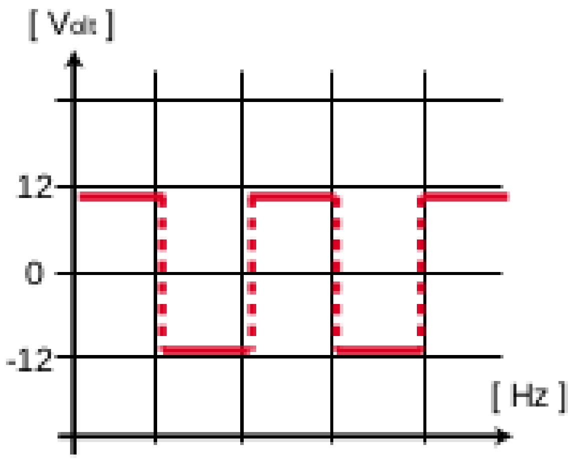


Figure 62: Reference output voltage signal of the stepper motor.

7.2 ECU self-adaptation

As mentioned before, the ECU:

- receives signals from the sensors
- processes these signals
- issues cotrol orders for the actuators.

In case the signals:

- are not received
- or detected as false,

then the ECU has to:

- self-adapt
- and find a way to keep the engine working for some time.

For satisfying the previous, ECU has to start reading and issuing signals that indicate a good working condition of the engine. The lab supervisor provided with the empirical information of a procedure that the ECU learns the components of the engine and most importantly the phonic wheel with rpm sensor.

In this procedure the phonic wheel needs to be synchronized with the ECU, because it is this specific component that gives information about the rpm. The procedure is explained as follows:

- Connection of the led mil[70]. When the led is on, it indicates the non-reading of the rpm sensor.
- Connection of an indicator of rpm[71].
- Turning the key in the position that the battery supplies the circuits of the engine and ECU. The led mil should be on.
- Waiting for the engine to warm up.
- Opening the throttle plate at least 3 times. Each time should reach to range 5000 ÷ 6000 rpm.
- If the led mil is still on, repetition of the previous step.
- Finally, turning the key in the posistion off[72].

The procedure is over and ECU is able to recognize and analyze the signals from the rpm.
It would be important to mention that if the ECU cannot read the rpm signals, then it cannot start the spark-ignition and the injectors actuation.

70 The led mil is connected to the ECU and to a common node betwwen the main relay and the secondare relay of the sensors/ECU circuit.
71 Multiecuscan diagnostics because it gives more accurate results.
72 The position, which disconnects the battery from the rest of the circuits.

Chapter 8 Testing procedure

In this chapter, it is provided the testing procedure. After integrating the test-bench, the next step is the verification:

- that the system actually works
- and that all the components work and contribute in the circuit,

with the intention of reading the outputs of this testing and understanding whether the engine works well.

The testing procedure is presented in the following steps:

- Connector for exporting signals
- Verification with Bosch diagnostics
- Multiecuscan diagnostics for tuning ECU
- First tryouts for locating problems
- Final testing for verification
- Overcoming TDC & lambda sensors

8.1 Connector for exporting signals

The majority of the parts, which were used are taken from different demolished cars. As a consequence, at the moment of developing the connection of the electrical and electronic circuits, it was understood that there was a connector, in the intake manifold, without any indication of what exactly it is planned for.
At first, it was assumed that it is probably the EOBD connector. But later, after verifying this assumption, the outcome was the table 25, in which there are presented:

- the distinction of the cables by color
- the connected element.

The verification was held with the help of a multimeter, in the selection of the signal indicator, while examining each component of the test-bench.

Cable color	Connected component
Yellow & white	Oil existance
White & brown	Connecting the two circuits
Grey & red	Temperature sensor
Yellow & black	Canister
Grey & yellow	Ground pinout of EOBD

Table 25: Analysis of the exporting signals connector.

8.2 Verification with Bosch diagnostics

After integrating the whole test-bench, the next step is to verify that the:

- engine is able to turn on
- ECU is being supplied
- components are being supplied
- ECU recognizes the signals of all the components.

For satisfying all the previous verifications, ECU is connected via EOBD to the hardware of the Bosch diagnostics. With the help of the Bosch Diagnostics software, it is obvious that the:

- components are being recognized
- and some errors are detected.

In this phase, both of the previous are a good sign, because:

- ECU is able to communicate with the components
- the errors can be analyzed later, with the Multiecuscan diagnostics.

Moreover, these errors are due to ECU, which is not yet synchronized.

8.3 Multiecuscan diagnostics for tuning ECU

In this step, the procedure for ECU self-adaptation was performed. This specific procedure was analyzed in the chapter 7.

For the completion of this step the multiecuscan was used, during which it was understood that the ECU could not work. The problem was that the ECU was in the mode of the locked immobilazer[73]. In the figure 63, it is visible the diagnosis of this specific software, with the explanations that gave the indication of the ECU problem. As a result, the ECU was sent to a specialist, who unlocked the immobilizer.

```
ECU ISO Code: 0D 07 13 80 7C
02/05/2018 10:23:54
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
---------------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

READING ERROR CODES:
1: U1600 - Electronic key
ERROR DETAILS:
Electronic key code: Not received
Engine temperature: 24 °C
Intake pressure: 0 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.

Anomaly concerning the electronic key ECU immobilizer function. The electronic key ECU has not received the key code or the code is not
included among the memorized ones.
Possible causes:
- Key non original or broken
- Ignition coil antenna disconnected or damaged
- Electronic key ECU supply
The reason for this fault is that ECU has received invalid signal from the sensor. The fault is present now. Take appropriate action to
fix this sensor fault. Dashboard warning light was not activated for this fault.
2: P0230 - Fuel pump relay
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 24 °C
Engine speed: 0 rpm
Intake pressure: 0 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.

The Fuel Pump relay control circuit has a defect. Check for opens, shorts and weak connections:
- The control circuit and connectors between the relay and the ECU
- The relay itself
- The ECU and driver stage ground and power supplies
```

Figure 63: ECU diagnosis 2/5/18.

During the procedure of the ECU tuning, the multiecuscan hardware & software had to be used as an indicator of the rpm[74], as seen in the figure 64. As it was expected, after the test performance the needed rpm was verified. With the explanations of the lab supervisor, it was obvious that:

73 When the vehicle is under theft situation the ECU gets locked in order to prevent the engine from working.

74 Providing the value of the rpm with its every change.

- the test was successful
- no need for repetition,

when the led mil[75] turned off. After this step is fulfilled, we can move on to the next step.

```
14/05/2018 14:49:46
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
SIMULATION MODE!!!
--------------------------------------------------------------

ECU ISO code: FD 86 15 01 6E
FIAT drawing number: 55188214
Hardware number: 0281011421
Hardware version: 00
Software number: 1037367790
Software version: A044
Homologation number:
ECU programming date: 07/13/2003

READING PARAMETERS:
Engine speed: 63 rpm

READING PARAMETERS:
Engine speed: 69 rpm

READING PARAMETERS:
Engine speed: 37 rpm

READING PARAMETERS:
Engine speed: 7 rpm

READING PARAMETERS:
Engine speed: 46 rpm

READING PARAMETERS:
Engine speed: 91 rpm

READING PARAMETERS:
Engine speed: 61 rpm

READING PARAMETERS:
Engine speed: 4 rpm

READING PARAMETERS:
Engine speed: 72 rpm
```

Figure 64: ECU diagnosis 14/5/18.

8.4 First testing tryouts

In this step the engine is ready for the first testing tryouts, which are used for locating problems and faulty components. The four testing attempts will be provided and explaned as follows. The diagnostics system used is the Multicusan, because it is important to record the outcomes:

- in text files
- and as raw numbers.

In this sub-chapter, only the outcomes in the form of raw numbers will be presented, because they are the appropriate representations for the information needed.

8.4.1 First testing attempt

In the first testing attempt, the engine is turned on but the rpm start increasing without moving the throttle valve. The only way for stopping the engine is to pull off the transformers[76]. The first tryout is composed by two testings, in which the components that were measured are listed below.

[75] Indicator for the success of the ECU learning.
[76] If no transformers, then no spark.

First testing components:

- Time in[sec]
- Engine speed in [rpm]
- Spark advance in [deg]
- Injection time in [ms]

Second testing componnets:

- Time in [sec]
- Battery voltage in [V]
- Engine speed in [rpm]
- Spark advance in [deg]
- Knock sensor signal (Cyl. 1) in [V]
- Knock sensor signal (Cyl. 2) in [V]
- Knock sensor signal (Cyl. 3) in [V]
- Knock sensor signal (Cyl. 4) in [V]

In the figure:

- 65, it is provided the first testing
- 66, it is given the second testing.

Time	Engine speed	Spark advance	Injection time
sec	rpm	deg.	ms
0,00	0	-53,000	0
0,56	0	-53,000	0
1,08	0	-53,000	0
1,59	0	-53,000	0
2,11	0	-53,000	0
2,62	0	-53,000	0
3,14	0	-53,000	0
3,65	0	-53,000	0
4,17	0	-53,000	0
4,68	0	-53,000	0
5,19	0	-53,000	0
5,71	0	-53,000	0
6,23	0	-53,000	0
6,77	0	-53,000	0
7,30	0	-53,000	0
7,86	0	-53,000	0
8,38	0	-53,000	0
8,89	0	-53,000	0
9,41	0	-53,000	0
9,94	0	-53,000	0
10,45	0	-53,000	0
11,00	0	-53,000	0
11,51	0	-53,000	0
12,03	0	-53,000	0
12,58	0	-53,000	0
13,10	0	-53,000	0
13,61	0	-53,000	0
14,21	0	-53,000	0
14,73	0	-53,000	0
15,24	0	-53,000	0
15,81	0	-53,000	0

Figure 65: First testing.

Time	Battery voltage	Engine speed	Spark advance	Timing (calculated)	Knock sensor signal (Cyl. 1)	Knock sensor signal (Cyl. 2)	Knock sensor signal (Cyl. 3)	Knock sensor signal (Cyl. 4)
sec	V	rpm	deg.		V	V	V	V
0	11,8	0	-3,4	-2,3	2,889	2,9622	0,1074	0,1122
1,32	11,8	0	-3,4	-2,3	2,9085	2,928	0,1074	0,1171
2,63	11,8	0	-3,4	-2,3	2,9475	2,9036	0,1074	0,1122
3,93	11,8	0	-3,4	-2,3	2,9329	2,9426	0,1074	0,1122
5,25	11,8	0	-3,4	-2,3	2,9085	2,9524	0,1122	0,1122
6,56	11,8	0	-3,4	-2,3	2,9768	2,9378	0,1122	0,1122
7,87	11,8	0	-3,4	-2,3	2,9329	2,889	0,1122	0,1122
9,18	11,8	0	-3,4	-2,3	2,8938	2,9134	0,1074	0,1122
10,51	11,8	0	-3,4	-2,3	2,8938	2,8938	0,1122	0,1171
11,82	11,8	0	-3,4	-2,3	2,8792	2,8987	0,1122	0,1122
13,12	11,8	0	-3,4	-2,3	2,9036	2,8938	0,1122	0,1122
14,43	11,8	0	-3,4	-2,3	2,8987	2,8938	0,1122	0,1122
15,76	11,8	0	-3,4	-2,3	2,9719	2,9231	0,1122	0,1171
17,07	11,8	0	-3,4	-2,3	2,889	2,9231	0,1074	0,1171
18,39	11,8	0	-3,4	-2,3	2,8987	2,9036	0,1122	0,1171
19,69	11,8	0	-3,4	-2,3	2,8938	2,8938	0,1122	0,1122
21,01	11,8	0	-3,4	-2,3	2,9426	2,9036	0,1122	0,1122
22,32	11,8	0	-3,4	-2,3	2,9182	2,8938	0,1074	0,1122
23,64	11,8	0	-3,4	-2,3	2,8987	2,9231	0,1122	0,1122
24,96	11,8	0	-3,4	-2,3	2,8938	2,8938	0,1074	0,1122
26,27	11,8	0	-3,4	-2,3	2,9231	2,9085	0,1074	0,1122
27,59	11,8	0	-3,4	-2,3	2,9134	2,9036	0,1122	0,1122
28,91	11,8	0	-3,4	-2,3	2,8938	2,928	0,1122	0,1171
30,22	11,8	0	-3,4	-2,3	2,9329	2,9622	0,1122	0,1171
31,54	11,8	0	-3,4	-2,3	2,9134	2,9036	0,1074	0,1122
32,86	11,8	0	-3,4	-2,3	2,9036	2,928	0,1074	0,1122
34,18	11,8	0	-3,4	-2,3	2,8938	2,9329	0,1074	0,1171
35,5	11,8	0	-3,4	-2,3	2,9426	2,9134	0,1074	0,1171
36,83	11,8	0	-3,4	-2,3	2,9182	2,9426	0,1122	0,1122
38,15	11,8	0	-3,4	-2,3	2,9036	2,9231	0	0,1122
40,1	10,1	513	10	10	3,4014	4,3334	2,357	3,7576
41,48	10,2	670	10	10	4,7873	4,2505	3,255	5,2118
43,84	10,6	810	12,2	10	2,5718	8,823	0,9711	2,5571
45,84	12,1	1187	6,9	10	0,7808	0,6978	0,976	3,416
47,18	12,3	1470	6	5,6	0,7174	0,7271	0,976	3,7674

Figure 66: Second testing.

8.4.2 Second testing attempt

In the second testing attempt, the target is to locate the exact reason for the problem of the turning off, of the engine. The first solution is swiching off the key, which did not work. Once more pulling off the transformers stopped the engine. This tryout is composed by three testings, in which the components that were measured are listed below.

First testing components:

- Time in [sec]
- Battery voltage in [V]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Air temperature in [°C]
- Throttle position in [deg.]
- Throttle position in [%]
- Stepper motor in [steps]
- Engine status

Second & third testing componnets:

- Time in [sec]
- Battery voltage in [V]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Air temperature in [°C]
- Throttle position in [deg.]
- Throttle position in [%]
- Stepper motor in [steps]

In the figure:

- 67, it is provided the first testing.
- 68, it is given the second testing.
- 69, it is presented the third testing.

Time	Battery voltage	Engine speed	Engine temperature	Air temperature	Throttle position	Throttle position	Idle actuator (Step m	Engine status
sec	V	rpm	°C	°C	deg.	%	steps	
0,00	119,000	0	260,000	250,000	0	0	1,290,000	Stalled
1,30	119,000	0	260,000	250,000	0	0	1,290,000	Stalled
2,61	119,000	0	260,000	250,000	0	0	1,290,000	Stalled
3,91	119,000	0	260,000	250,000	0	0	1,290,000	Stalled
5,23	119,000	0	260,000	250,000	0	0	1,290,000	Running
6,70	124,000	21,470,000	260,000	250,000	0	0	1,150,000	Running
8,33	125,000	28,260,000	270,000	250,000	0	0	890,000	Running
10,14	125,000	27,080,000	270,000	260,000	1,000	0	930,000	Running
11,50	127,000	21,650,000	280,000	260,000	2,000	0	680,000	Running
13,35	126,000	21,520,000	280,000	260,000	1,000	0	910,000	Running
15,37	126,000	23,720,000	280,000	260,000	0	0	930,000	Running
16,76	127,000	14,790,000	280,000	260,000	1,000	0	900,000	Running
18,25	126,000	23,940,000	290,000	260,000	0	0	920,000	Running
20,37	127,000	22,620,000	290,000	260,000	1,000	0	560,000	Running
22,06	128,000	14,980,000	290,000	260,000	0	0	560,000	Running
23,53	128,000	13,460,000	290,000	260,000	1,000	0	560,000	Running
24,84	127,000	12,160,000	290,000	260,000	1,000	0	870,000	Running
26,14	120,000	0	290,000	260,000	2,000	0	1,270,000	Stalled
27,46	125,000	0	290,000	260,000	2,000	0	1,270,000	Stalled
28,77	124,000	0	290,000	260,000	2,000	0	1,280,000	Stalled
30,08	123,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
31,39	123,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
32,69	123,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
33,99	122,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
35,30	122,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
36,61	122,000	0	280,000	260,000	2,000	0	1,280,000	Stalled
37,92	122,000	0	270,000	260,000	2,000	0	1,280,000	Stalled
39,25	122,000	0	270,000	260,000	2,000	0	1,280,000	Stalled
40,55	122,000	0	270,000	260,000	2,000	0	1,280,000	Stalled
41,86	122,000	0	270,000	260,000	2,000	0	680,000	Stalled
43,16	122,000	0	270,000	260,000	2,000	0	0	Stalled

Figure 67: First testing.

Time	Battery voltage	Engine speed	Engine temperature	Air temperature	Throttle position	Throttle position	Idle actuator (Step m
sec	V	rpm	°C	°C	deg.	%	steps
0,00	120,000	0	290,000	260,000	0	0	1,270,000
1,16	120,000	0	290,000	260,000	0	0	1,270,000
2,31	120,000	0	290,000	260,000	0	0	1,270,000
3,46	120,000	0	290,000	260,000	0	0	1,270,000
4,62	120,000	0	290,000	260,000	0	0	1,270,000
5,77	120,000	0	290,000	260,000	0	0	1,270,000
6,93	120,000	0	290,000	260,000	0	0	1,270,000
8,08	120,000	0	290,000	260,000	0	0	1,270,000
9,24	120,000	0	290,000	260,000	0	0	1,270,000
10,39	120,000	0	290,000	260,000	0	0	1,270,000
11,55	120,000	0	290,000	260,000	0	0	1,270,000
12,70	120,000	0	290,000	260,000	0	0	1,270,000
13,85	120,000	0	290,000	260,000	0	0	1,270,000
15,01	120,000	0	290,000	260,000	0	0	1,270,000
16,15	120,000	0	290,000	260,000	0	0	1,270,000
17,30	120,000	0	290,000	260,000	0	0	1,270,000
18,45	120,000	0	290,000	260,000	0	0	1,270,000
19,59	120,000	0	290,000	260,000	0	0	1,270,000
20,75	120,000	0	290,000	260,000	0	0	1,270,000
21,89	120,000	0	290,000	260,000	0	0	1,270,000
23,04	120,000	0	290,000	260,000	0	0	1,270,000
24,21	120,000	0	290,000	260,000	0	0	1,270,000
25,36	120,000	0	290,000	260,000	0	0	1,270,000
26,51	120,000	0	290,000	260,000	0	0	1,270,000
27,66	120,000	0	290,000	260,000	0	0	1,270,000
28,81	120,000	0	290,000	260,000	0	0	1,270,000
29,97	120,000	0	290,000	260,000	0	0	1,270,000
31,12	120,000	0	290,000	260,000	0	0	1,270,000
32,27	120,000	0	290,000	260,000	0	0	1,270,000
33,43	120,000	0	290,000	260,000	0	0	1,270,000
34,66	120,000	0	290,000	260,000	0	0	1,270,000

Figure 68: Second testing.

Time	Battery voltage	Engine speed	Engine temperature	Air temperature	Injection time	Throttle position	Throttle position	Idle actuator (Step m
sec	V	rpm	°C	°C	ms	deg.	%	steps
0,00	120,000	0	330,000	260,000	0	0	0	1,250,000
1,31	120,000	0	330,000	260,000	0	0	0	1,250,000
2,61	120,000	0	330,000	260,000	0	0	0	1,250,000
3,92	120,000	0	330,000	260,000	0	0	0	1,250,000
5,23	120,000	0	330,000	260,000	0	0	0	1,250,000
6,54	120,000	0	330,000	260,000	0	0	0	1,250,000
7,86	120,000	0	330,000	260,000	0	0	0	1,250,000
9,16	120,000	0	330,000	260,000	0	0	0	1,250,000
10,48	120,000	0	330,000	260,000	0	0	0	1,250,000
11,79	120,000	0	330,000	260,000	0	0	0	1,250,000
13,15	120,000	0	330,000	260,000	196,920	0	0	1,200,000
14,58	124,000	16,240,000	330,000	260,000	89,580	0	0	1,080,000
15,91	130,000	4,770,000	340,000	260,000	0	2,000	0	1,230,000
17,22	122,000	0	340,000	260,000	0	2,000	0	1,230,000
18,52	121,000	0	340,000	260,000	0	2,000	0	1,230,000
19,84	121,000	0	340,000	260,000	0	2,000	0	1,230,000
21,14	121,000	0	340,000	260,000	0	2,000	0	1,230,000
22,46	121,000	0	340,000	260,000	0	2,000	0	1,240,000
23,76	120,000	0	330,000	260,000	0	2,000	0	1,240,000
25,08	120,000	0	330,000	260,000	0	2,000	0	1,240,000
26,39	120,000	0	330,000	260,000	0	2,000	0	1,240,000
27,70	120,000	0	330,000	260,000	0	2,000	0	1,240,000
29,01	120,000	0	330,000	260,000	0	2,000	0	1,240,000
30,32	120,000	0	330,000	260,000	0	2,000	0	1,240,000
31,63	120,000	0	330,000	260,000	0	2,000	0	1,240,000
32,94	120,000	0	330,000	260,000	0	2,000	0	1,240,000
34,26	120,000	0	330,000	260,000	0	2,000	0	1,240,000
35,56	120,000	0	330,000	260,000	0	2,000	0	1,240,000
36,88	120,000	0	330,000	260,000	0	2,000	0	1,240,000
38,17	120,000	0	330,000	260,000	0	2,000	0	1,240,000
39,48	120,000	0	330,000	260,000	0	2,000	0	1,240,000

Figure 69: Third testing.

8.4.3 Third testing attempt

In the third testing attempt, for finding the solution for the previous problem, the solution below is followed:

- switching off the key
- pressing the emergency button
- taking off the negative cable of the battery
- lastly pulling off the transformers.

It is understood that only the transformers can stop the engine. This tryout is composed by 2 testings, in which the components that were measured are listed as follows.

First & second testing components:

- Time in [sec]
- Battery voltage in [V]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Injection time in [ms]
- Throttle position in [deg]
- Throttle position in [%]
- Idle actuator (Step motor) in [steps]

In the figure:

- 70, it is provided the first testing.
- 71, it is given the second testin.

Time	Battery voltage	Engine speed	Engine temperature	Injection time	Throttle position	Throttle position	Idle actuator (Step n
sec	V	rpm	°C	ms	deg.	%	steps
0,00	122,000	0	470,000	0	0	0	1,150,000
1,15	122,000	0	470,000	0	0	0	1,150,000
2,30	122,000	0	470,000	0	0	0	1,150,000
3,46	122,000	0	470,000	0	0	0	1,150,000
4,63	122,000	0	470,000	0	0	0	1,150,000
5,78	122,000	0	470,000	0	0	0	1,150,000
6,94	122,000	0	470,000	0	0	0	1,150,000
8,10	122,000	0	470,000	0	0	0	1,150,000
9,24	122,000	0	470,000	0	0	0	1,150,000
10,40	122,000	0	470,000	0	0	0	1,150,000
11,56	122,000	0	470,000	0	0	0	1,150,000
12,71	96,000	0	470,000	188,800	0	0	1,150,000
13,97	126,000	22,160,000	470,000	67,580	0	0	1,010,000
15,12	126,000	26,990,000	470,000	54,180	0	0	790,000
16,27	127,000	26,490,000	470,000	52,400	0	0	800,000
17,42	126,000	27,000,000	470,000	49,660	1,000	0	870,000
19,25	125,000	16,320,000	470,000	73,460	1,000	0	760,000
20,57	124,000	11,730,000	470,000	74,100	1,000	0	790,000
21,76	125,000	16,210,000	480,000	0	1,000	0	780,000
23,14	125,000	17,870,000	470,000	71,520	1,000	0	800,000

Figure 70: First testings.

Time	Battery voltage	Engine speed	Engine temperature	Injection time	Throttle position	Throttle position	Idle actuator (Step m
sec	V	rpm	°C	ms	deg.	%	steps
0,00	125,000	19,850,000	480,000	0	0	0	870,000
1,16	126,000	16,670,000	480,000	101,120	0	0	470,000
2,73	125,000	19,890,000	480,000	0	1,000	0	850,000
4,39	126,000	15,960,000	480,000	66,780	1,000	0	770,000
5,70	125,000	12,600,000	480,000	80,100	0	0	760,000
6,86	125,000	12,360,000	480,000	79,180	1,000	0	820,000
8,01	125,000	13,570,000	480,000	89,880	1,000	0	850,000
9,17	125,000	15,180,000	480,000	107,800	0	0	740,000
10,32	125,000	16,810,000	480,000	100,280	0	0	560,000
11,47	126,000	17,770,000	480,000	0	0	0	460,000
12,63	125,000	20,600,000	480,000	0	1,000	0	700,000
13,78	126,000	21,860,000	480,000	0	1,000	0	730,000
15,09	126,000	19,590,000	490,000	0	1,000	0	690,000
16,75	125,000	22,220,000	480,000	105,100	0	0	860,000
17,90	125,000	16,580,000	480,000	103,000	0	0	830,000
19,22	125,000	17,240,000	490,000	100,580	0	0	840,000
20,52	125,000	16,850,000	490,000	98,900	0	0	680,000
21,71	125,000	18,150,000	490,000	12,460	0	0	460,000
22,86	125,000	20,670,000	490,000	0	1,000	0	860,000
24,18	125,000	20,720,000	490,000	0	1,000	0	760,000
25,34	128,000	17,100,000	490,000	0	1,000	0	780,000
26,50	129,000	13,960,000	490,000	70,200	1,000	0	820,000
27,66	127,000	14,520,000	490,000	96,320	0	0	860,000
29,13	127,000	13,260,000	490,000	99,540	1,000	0	850,000
30,46	124,000	15,360,000	490,000	109,940	0	0	720,000
32,16	124,000	17,240,000	490,000	12,700	0	0	780,000
33,31	126,000	12,870,000	490,000	88,100	1,000	0	800,000
34,63	124,000	17,570,000	490,000	0	0	0	550,000
35,94	124,000	18,650,000	490,000	100,180	0	0	460,000
37,26	125,000	20,290,000	490,000	0	1,000	0	630,000

Figure 71: Second testings.

8.4.4 Fourth testing attempt

In the fourth testing attempt, the solution of pulling off the relay was decided to be followed and the engine stopped immediately. It is understood that the problem is located at the circuit of the main relay. This tryout is composed by 2 testings, in which the components that were measured are listed as follows.

First & second testing components:

- Time in [sec]
- Battery voltage in [V]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Throttle position in [deg]
- Throttle position in [%]

In the figure:

- 72, it is provided the first testing.
- 73, it is given the second testing.

Time	Battery voltage	Engine speed	Engine temperature	Throttle position	Throttle position
sec	V	rpm	°C	deg.	%
0,00	122,000	0	720,000	1,000	0
0,84	122,000	0	720,000	1,000	0
1,68	122,000	0	720,000	1,000	0
2,53	122,000	0	720,000	1,000	0
3,38	122,000	0	720,000	1,000	0
4,21	122,000	0	720,000	1,000	0
5,05	122,000	0	720,000	1,000	0
5,90	122,000	0	720,000	1,000	0
6,74	122,000	0	720,000	1,000	0
7,58	122,000	0	720,000	1,000	0
8,43	122,000	0	720,000	1,000	0
9,28	122,000	0	720,000	1,000	0
10,10	122,000	0	720,000	1,000	0

Figure 72: First testings.

Time	Battery voltage	Engine speed	Engine temperature	Throttle position	Throttle position
sec	V	rpm	°C	deg.	%
0,00	122,000	0	720,000	695,000	0
0,85	122,000	0	720,000	1,000	0
1,69	122,000	0	720,000	1,000	0
2,53	122,000	0	720,000	1,000	0
3,37	122,000	0	720,000	1,000	0
4,21	122,000	0	720,000	1,000	0
5,05	122,000	0	720,000	1,000	0
6,37	101,000	2,470,000	720,000	0	0
7,21	125,000	14,000,000	720,000	0	0
8,26	123,000	13,850,000	720,000	0	0
9,25	124,000	14,380,000	720,000	1,000	0
10,17	124,000	12,740,000	720,000	1,000	0
11,25	123,000	11,200,000	720,000	1,000	0
12,09	123,000	13,090,000	710,000	0	0
13,14	122,000	13,470,000	710,000	1,000	0
14,40	125,000	9,860,000	710,000	1,000	0
15,66	123,000	11,760,000	710,000	1,000	0
16,54	123,000	11,250,000	710,000	1,000	0
17,53	123,000	9,640,000	710,000	1,000	0
18,37	124,000	8,130,000	710,000	1,000	0
19,65	124,000	8,310,000	710,000	1,000	0
21,01	123,000	10,750,000	710,000	1,000	0
21,83	122,000	8,860,000	710,000	0	0
22,66	122,000	8,930,000	710,000	201,000	0
23,53	121,000	4,860,000	710,000	5,000	0
24,36	121,000	6,330,000	710,000	4,000	0
25,36	124,000	9,570,000	710,000	2,000	0
26,23	123,000	8,870,000	710,000	2,000	0
27,56	121,000	8,300,000	710,000	3,000	0
28,39	123,000	8,440,000	710,000	2,000	0

Figure 73: Second testings.

8.5 Final testings

In this sub-chapter, it is provided the final testing with problem:

- solving
- or bypassing.

Thus, it will be explained the last steps for completing the testing procedure.

8.5.1 Fuel pump problem

After solving that all the previous problems, it is possible to continue with the testings, which provide the outcomes in the figure 74. This specific testing outcome is in the text form, which is extracted by the Multiecuscan Diagnostics, and give the information of the problem in the fuel pump. By changing the fuel pump, the problem is solved.

```
ECU ISO Code: 0D 07 13 80 7C
31/05/2018 14:39:40
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
--------------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

EXECUTING ACTUATOR...
Injector 1
COMPLETED


EXECUTING ACTUATOR...
Injector 2
COMPLETED


EXECUTING ACTUATOR...
Injector 3
COMPLETED


EXECUTING ACTUATOR...
Injector 4
COMPLETED


EXECUTING ADJUSTMENT...
Self-adaptation reset
FAILED TO EXECUTE
Incorrect conditions to run this test!

READING ERROR CODES:
1: P0230 - Fuel pump relay
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 23 °C
Engine speed: 0 rpm
Intake pressure: 960 mBar
Engine status: Off
Throttle position: 0 deg.
Spark advance: 0,0 deg.
```

Figure 74: Fuel pump problem diagnostics.

8.5.2 Test-bench testing

After solving the problem with the fuel pump, the test-bench is ready to be under test in order to provide outcomes of a good working engine. This happens with some tryouts, during which all the components are presented as follows.

First tryout components:

- Time in [sec]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Air temperature in [°C]
- Spark advance in [deg]
- Timing (calculated)
- Injection time in [ms]
- Coil 1 charge time in [ms]
- Coil 2 charge time in [ms]
- Intake pressure in [mBar]

- Throttle position in [deg]
- Throttle position in [%]

Second tryout components:

- Time in [sec]
- Engine speed in [rpm]
- Engine temperature in [°C]
- Injection time in [ms]
- Misfires detected
- Throttle position in [deg]
- Lambda 1 signal (Pre-Cat.) in [V]
- Lambda sensor 1 integrator in [%]
- Lambda 1 status (Pre-Cat.)
- Lambda 1 diagnosis (Pre-Cat.)
- Canister fill in [%]

In the figure:

- 75, it is provided the first tryout.
- 76, it is given the second tryout.

Time	Engine speed	Engine temperature	Air temperature	Spark advance	Timing (calculated)	Injection time	Coil 1 charge time	Coil 2 charge time	Intake pressure	Throttle position	Throttle position
sec	rpm	°C	°C	deg.		ms	ms	ms	mBar	deg.	%
0,00	8,090,000	740,000	400,000	103,000	100,000	37,980	30,460	29,740	3,900,000	3,000	0
1,79	8,100,000	740,000	400,000	121,000	100,000	37,100	30,080	29,360	3,930,000	2,000	0
3,59	8,270,000	740,000	400,000	135,000	100,000	38,380	30,180	29,460	3,930,000	2,000	0
5,38	8,220,000	740,000	400,000	134,000	100,000	38,020	30,620	29,840	3,900,000	2,000	0
7,18	8,150,000	740,000	400,000	104,000	100,000	37,500	30,040	29,540	3,910,000	2,000	0
9,12	8,250,000	740,000	400,000	141,000	100,000	37,460	30,420	29,600	3,900,000	2,000	0
10,92	8,200,000	740,000	400,000	128,000	100,000	37,900	30,540	29,660	3,890,000	3,000	0
13,22	8,080,000	740,000	400,000	106,000	100,000	38,620	30,500	29,900	3,880,000	2,000	0
15,01	8,250,000	740,000	400,000	140,000	100,000	37,380	30,460	30,040	3,880,000	2,000	0
16,79	8,190,000	740,000	400,000	115,000	100,000	37,660	30,880	29,880	3,860,000	3,000	0
19,09	8,110,000	740,000	400,000	13,000	227,000	70,540	30,320	30,500	5,230,000	147,000	0
20,89	34,910,000	740,000	400,000	339,000	300,000	71,820	32,160	32,840	6,070,000	120,000	0
22,68	51,540,000	740,000	400,000	320,000	476,000	0	30,520	29,740	2,070,000	3,000	0
24,47	22,710,000	740,000	410,000	251,000	476,000	30,660	30,100	29,360	8,990,000	211,000	0
26,74	40,000	740,000	410,000	278,000	332,000	39,240	33,440	31,740	1,810,000	3,000	0
28,52	45,640,000	740,000	410,000	330,000	497,000	0	30,340	29,140	2,160,000	3,000	0
30,32	17,850,000	740,000	410,000	-1,000	131,000	41,800	31,300	30,880	4,620,000	89,000	0
32,12	19,490,000	740,000	420,000	372,000	385,000	29,520	30,760	30,040	2,100,000	3,000	0
33,91	18,950,000	740,000	410,000	24,000	129,000	35,640	30,180	29,740	3,650,000	2,000	0
35,70	10,410,000	740,000	420,000	128,000	100,000	41,260	30,120	29,740	3,830,000	2,000	0
37,50	9,030,000	740,000	410,000	104,000	100,000	42,760	30,780	29,900	3,880,000	3,000	0
39,30	8,450,000	740,000	420,000	105,000	100,000	51,320	31,560	30,900	3,850,000	2,000	0
41,10	9,420,000	740,000	410,000	107,000	100,000	49,460	30,560	30,580	4,050,000	2,000	0
42,89	8,180,000	740,000	410,000	203,000	100,000	60,480	31,540	30,740	4,210,000	3,000	0
44,69	8,310,000	740,000	410,000	70,000	159,000	66,200	31,400	30,520	2,850,000	3,000	0
46,48	9,650,000	740,000	410,000	125,000	176,000	48,040	31,480	30,940	2,760,000	18,000	0
48,28	11,630,000	740,000	410,000	159,000	167,000	43,500	31,260	30,660	3,180,000	20,000	0
50,07	10,980,000	740,000	410,000	142,000	145,000	43,460	30,900	30,700	3,390,000	20,000	0
51,86	10,970,000	740,000	410,000	144,000	113,000	43,360	31,300	30,640	3,590,000	17,000	0
53,66	10,270,000	740,000	410,000	136,000	139,000	45,220	31,500	30,520	3,300,000	21,000	0
55,45	11,180,000	750,000	410,000	141,000	144,000	44,320	31,000	30,580	3,410,000	33,000	0

Figure 75: First tryout components.

Time	Engine speed	Engine temperature	Injection time	Misfires detected	Throttle position	Lambda 1 signal (Pr	Lambda sensor 1 int	Lambda 1 status (Pre	Lambda 1 diagnosis	Canister fill
sec	rpm	°C	ms		deg.	V	%			%
0,00	0	520,000	0	NO	5,000	0	10,000	Open Loop	Bottom Limit	0
1,63	0	520,000	0	NO	5,000	0	10,000	Open Loop	Bottom Limit	0
3,25	0	520,000	0	NO	5,000	0	10,000	Open Loop	Bottom Limit	0
4,88	0	520,000	0	NO	5,000	0	10,000	Open Loop	Bottom Limit	0
7,06	0	520,000	193,200	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
8,84	5,550,000	520,000	126,820	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
10,47	7,300,000	520,000	120,920	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
12,28	7,950,000	520,000	112,600	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
14,07	8,960,000	520,000	112,080	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
15,84	8,100,000	520,000	109,240	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
17,46	9,380,000	520,000	106,280	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
19,13	10,960,000	520,000	90,740	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
20,94	11,250,000	520,000	86,140	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
23,47	18,540,000	520,000	62,680	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
25,72	19,670,000	520,000	0	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
27,35	18,210,000	520,000	0	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
29,53	12,720,000	520,000	68,420	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
31,39	16,260,000	520,000	0	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
33,22	22,700,000	520,000	0	NO	1,000	0	10,000	Open Loop	Bottom Limit	0
35,51	22,320,000	520,000	103,080	NO	1,000	0	10,000	Open Loop	Bottom Limit	0
37,14	13,990,000	520,000	126,500	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
39,19	13,480,000	520,000	66,800	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
40,99	10,560,000	520,000	101,240	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
42,65	12,160,000	520,000	109,860	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
44,61	12,860,000	520,000	64,320	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
46,24	13,640,000	520,000	72,040	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
48,70	16,810,000	520,000	13,080	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
50,69	12,720,000	520,000	104,420	NO	2,000	0	10,000	Open Loop	Bottom Limit	0
52,34	16,390,000	520,000	94,680	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
54,12	32,140,000	520,000	0	NO	3,000	0	10,000	Open Loop	Bottom Limit	0
55,75	20,730,000	530,000	0	NO	39,000	0	10,000	Open Loop	Bottom Limit	0

Figure 76: Second tryout components.

8.5.3 Bypassing components

After getting the final outcomes there are two problems that should be defined, which are focused on bypassing the:

- TDC sensor
  In the figure 77, it is provided the information that the TDC position of each piston can be defined by the ECU just by reading and synchronizing the signals of the rpm sensor. In the table 26, it is presented the association between numbers and associated parameter of the previous figure.

- Lambda sensor
  For bypassing the lambda sensor, the stochiometric ratio is used. In this way, the ECU adjusts the fuel-air mixture.

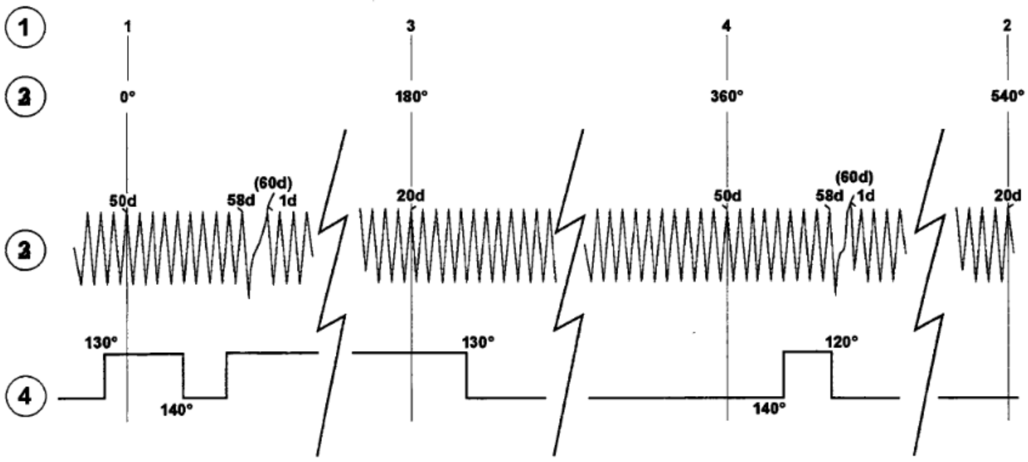


Figure 77: Definition of TDC position.

Number	Associated parameter
1	Cylinder TDC
2	Crankshaft angles
3	Crankshaft phonic wheel signal[77]
4	Camshaft wheel signal[78]

Table 26: Associated numbers & parameters of the figure 77.

[77] Rpm sensor.
[78] Engine timing.

Chapter 9 Data Processing

In this chapter, the procedure for data processing will be explained. This means that the following information will be presenting:

- the form of the extracted data
- the required representation of the processed data
- the procedure for this process

9.1 Representation of extracted data

The Multiecuscan diagnostics, via its software, extracts data from the ECU. These data are being presented in the following forms of representation:

- raw numerical[79]
- as an explanation of the faulty components[80]

In the figures 78 & 79, it is able to understand the two above representations. It is important to mention that, during the experiment it is understood that the delay of representation of the rpm changes is negligible, as the software provides sampling outputs in fixed time intervals.

9.2 Required representation of processed data

The required representation of the outputs, should be graphical. The reason is, as mentioned above, that it is easier to be understood and analyzed by students. As follows, a set of experiments should be performed, which will give a set of outputs. A specific procedure will be chosen and defined to process the data from the numerical to the graphical form, as explained in the following sub-chapter[81].

In the following figures[82], there are illustrated three graphical examples. The results can be seen in the table 27, in which the following are presented:

- number of figure
- title of plot
- explanation

[79] In excel compatible file.
[80] In text file.
[81] Sub-chapter 9.3Process data procedure.
[82] Referred to figures 80, 81 & 82.

Time	Engine speed	Engine temperature	Throttle position
sec	rpm	°C	deg.
0,00	15,850,000	320,000	1,000
0,52	20,850,000	320,000	3,000
1,03	18,570,000	320,000	1,000
2,04	22,180,000	320,000	3,000
2,56	14,760,000	320,000	1,000
3,15	17,250,000	320,000	1,000
3,99	19,080,000	320,000	1,000
4,53	18,710,000	320,000	3,000
5,27	18,470,000	320,000	0
5,79	21,490,000	320,000	3,000
6,30	18,390,000	320,000	1,000
6,99	19,890,000	320,000	3,000
7,50	19,320,000	320,000	3,000
8,18	17,510,000	320,000	2,000
9,01	22,890,000	320,000	3,000
9,53	12,570,000	320,000	2,000
10,07	23,650,000	320,000	3,000
10,78	15,500,000	320,000	2,000
11,54	21,530,000	320,000	3,000
12,06	17,550,000	320,000	1,000
12,73	18,540,000	320,000	3,000
13,56	18,870,000	320,000	1,000
14,11	20,300,000	320,000	1,000
14,62	21,310,000	320,000	3,000
15,15	13,830,000	320,000	1,000
16,05	21,480,000	320,000	3,000
16,58	16,250,000	320,000	3,000
17,80	19,090,000	320,000	3,000
18,33	14,910,000	320,000	1,000
19,33	18,560,000	320,000	3,000
19,84	18,950,000	320,000	3,000

Figure 78: Raw numerical representation.

```
ECU ISO Code: 0D 07 13 80 7C
01/06/2018 12:09:40
CONNECTED TO:
Fiat Palio Restyling 2 '04 1.1 8V
Magneti Marelli IAW 4AF/4EF/59F/5AF EOBD Injection
--------------------------------------------------------------

ECU ISO code: 0D 07 13 80 7C
FIAT drawing number: 55181151
Hardware number: IAW59FHW305
Hardware version: 00
Software number: 18080YZ
Software version: 0000
Homologation number: 59FM5
ECU programming date: 11/29/2002

READING ERROR CODES:
1: P0141 - Lambda 1 heater below catalyser
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 27 °C
Engine speed: 0 rpm
Intake pressure: 960 mBar
Engine status: Running
Throttle position: 0 deg.
Spark advance: 0,0 deg.

No help available
The reason for this fault is that ECU did not receive signal from the sensor. The fault is present now. Take appropriate action to fix
this sensor fault. Dashboard warning light was activated for this fault.
2: P0135 - Lambda 1 heater above catalyser
ERROR DETAILS:
Fault status: Open circuit
Engine temperature: 24 °C
Engine speed: 2450 rpm
Intake pressure: 512 mBar
Engine status: Running
Throttle position: 0 deg.
Spark advance: 40,0 deg.

The code is set when there is an open or a short in the Lambda Sensor heater relay circuit indicated by the code. This slows down the
Lambda sensor in reaching the operating temperature. Check the relay, connectors and wiring between the relay, ECU and the power supply.
The reason for this fault is that ECU did not receive signal from the sensor. The fault is not detected now, but it is stored in memory.
Clear fault codes, and observe for future appearance of the same fault. Dashboard warning light was activated for this fault.
3: P0340 - Camshaft position sensor
ERROR DETAILS:
Engine temperature: 27 °C
Engine speed: 475 rpm
Intake pressure: 960 mBar
Engine status: Running
Throttle position: 0 deg.
```

Figure 79: Text representation.

Figure	Title of plot	Explanation
80	Engine speed - time	It is associated to the ECU, which is not synchronized.
81	Engine temperature – time	It is associated to the engine, which is not working well.
82	Throttle position - time	It is associated to the engine, which is working well.

Table 27: Explanation of the example figures.

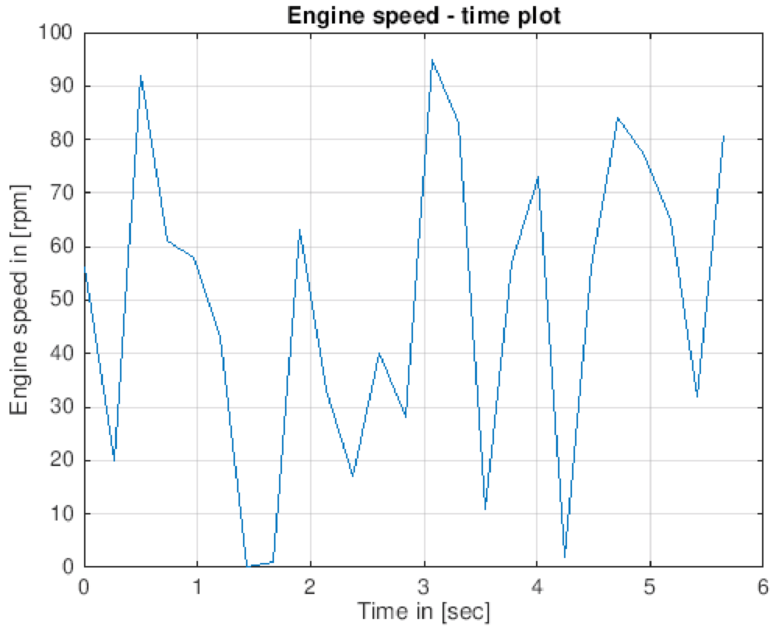


Figure 80: Engine speed – time plot.

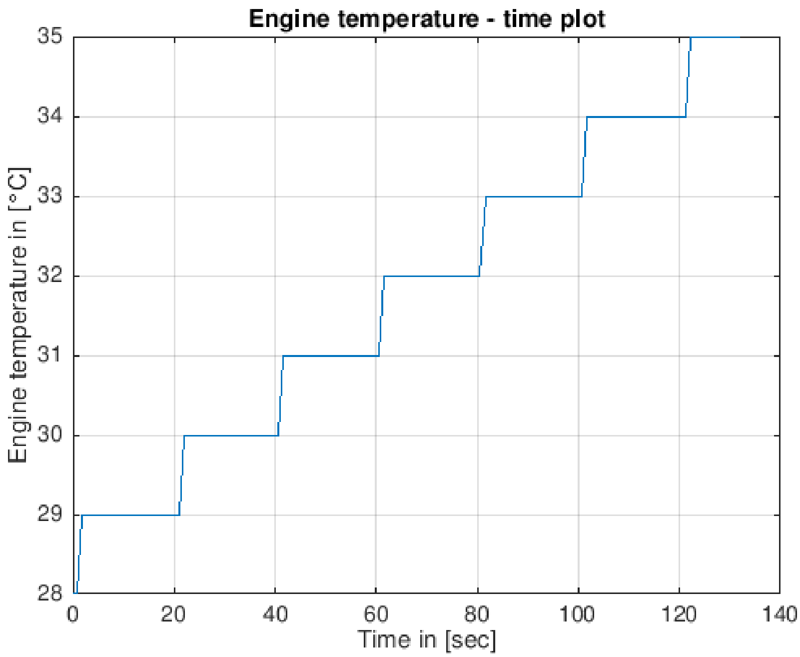


Figure 81: Engine temperature – time plot.

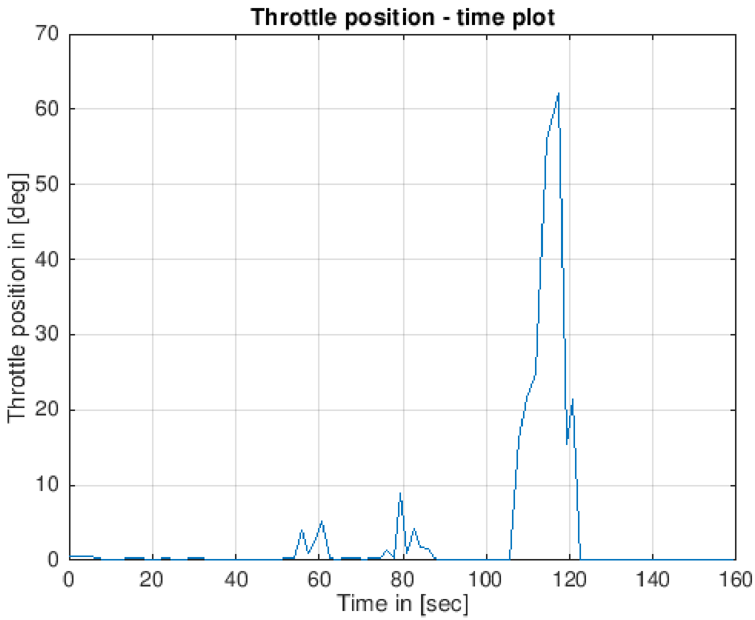


Figure 82: Throttle position – time plot.

9.3 Processing data procedure

The procedure that is analyzed in this sub-chapter, starts from the moment that the software Multiecuscan records the data during an experiment, and it follows the procedure:

- Store the data as a file with the extension .csv, which is composed by the:
  i. raw numbers
  ii. and names of the parameters under test.
- Manipulate the data in Matlab, which is chosen due to the fact that it is a familiar software for the team members. It is referred to the creation of a simple code, which is used to plot the specific parameters.
- Save the plots/graphical representations for analysis purposes.

In the figures 83 & 84, it are illustrated the example procedure. In the table 28, it is provided the association of the:

- figures
- and procedure steps.

Finally, a documentation of outcomes in graphical form can be stored. This documentation can be used for the results analysis part in the Chapter 10..

Figures	Procedure steps
83	Storing data in a .csv file extension.
84	Simple Matlab code for plotting.

Table 28: Explanation of procedure steps.

	A	B	C	D	E	F	G	H
1	Time	Battery voltage	Engine speed	Engine temperature	Injection time	Throttle position	Throttle position	Idle actuator (Step m
2	sec	V	rpm	°C	ms	deg.	%	steps
3	0,00	122,000	0	470,000	0	0	0	1,150,000
4	1,15	122,000	0	470,000	0	0	0	1,150,000
5	2,30	122,000	0	470,000	0	0	0	1,150,000
6	3,46	122,000	0	470,000	0	0	0	1,150,000
7	4,63	122,000	0	470,000	0	0	0	1,150,000
8	5,78	122,000	0	470,000	0	0	0	1,150,000
9	6,94	122,000	0	470,000	0	0	0	1,150,000
10	8,10	122,000	0	470,000	0	0	0	1,150,000
11	9,24	122,000	0	470,000	0	0	0	1,150,000
12	10,40	122,000	0	470,000	0	0	0	1,150,000
13	11,56	122,000	0	470,000	0	0	0	1,150,000
14	12,71	96,000	0	470,000	188,800	0	0	1,150,000
15	13,97	126,000	22,160,000	470,000	67,580	0	0	1,010,000
16	15,12	126,000	26,990,000	470,000	54,180	0	0	790,000
17	16,27	127,000	26,490,000	470,000	52,400	0	0	800,000
18	17,42	126,000	27,000,000	470,000	49,660	1,000	0	870,000
19	19,25	125,000	16,320,000	470,000	73,460	1,000	0	760,000
20	20,57	124,000	11,730,000	470,000	74,100	1,000	0	790,000
21	21,76	125,000	16,210,000	480,000	0	1,000	0	780,000
22	23,14	125,000	17,870,000	470,000	71,520	1,000	0	800,000

Figure 83: File .csv extension.

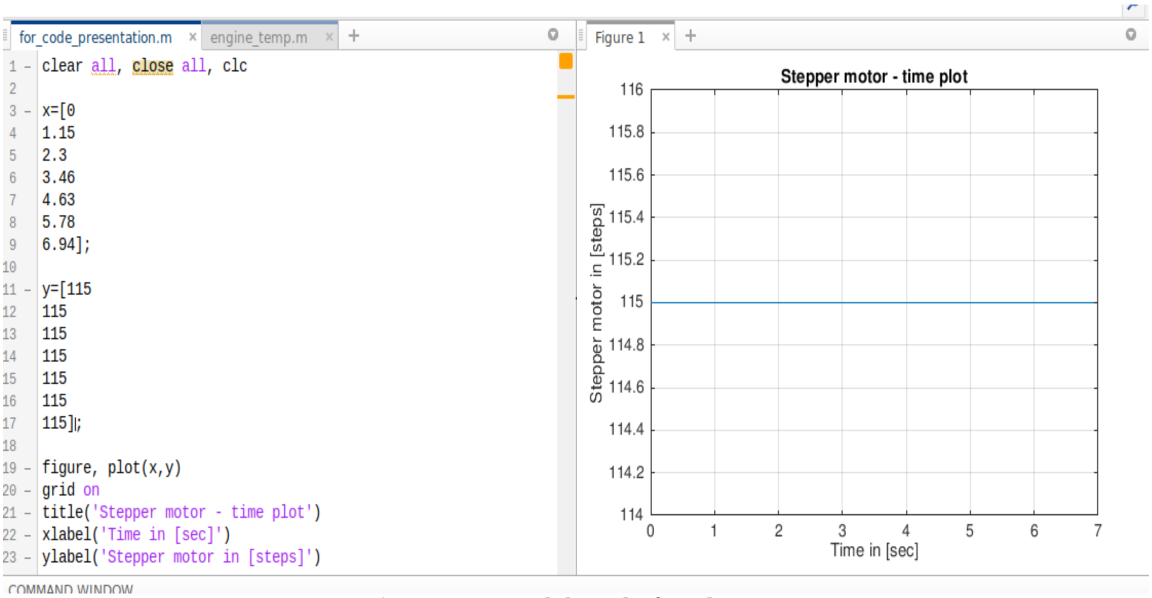


Figure 84: Matlab code for plotting.

9.4 Conclusion

In this chapter, it is analyzed the procedure and process of manipulating the raw numerical results and transforming them to graphical representations. For achieving this, it is important to follow a specific procedure that ideally should be as easy as possible to be understood by the students. The outcome of this procedure is a documentation of graphical representations, which will be used for the results analysis part.

Chapter 10 Results Analysis

This chapter, focuses on the:

- analysis
- explanation
- comparison

of the results obtained from the performed tests.

The results, with their analysis, are divided in the three following cases:

- Bosch Diagnostics
- Multiecuscan :
  i. The startup of the engine
  ii. Engine working efficiently
- Simulink model[83].

As a consequence of the analysis, a comparison between the most critical points will take place.

10.1 Results and Analysis

The number of the obtain results is critically big, thus it is impossible to illustrate and analyze all of them. For this reason, the most important results will be presented. As it is mentioned above the results will be presented in four different cases. For the first case, the results will be:

- obtained by the software Bosch diagnostics
- and illustrated collectively,

since no detailed numbers are illustrated. But for the results of the:

- Multiecuscan, an analysis of each component separately will be presented.
- Simulink model, engine speed will be provided[84].

10.1.1 Bosch diagnostics results

In this case, the results are obtrained by an engine in a good working condition. And they are:

- dependent on time
- triggered and alternated by the throttle pedal

As mentioned above, Bosch Diagnostics provides not detailed enough outcomes, which are presented in the three following graphs. One important detail is that, due to the fact that this specific software introduces an important delay, then in the performed experiments it was possible to represent only the parameters illustrated in the following graphs.

1. For representing and analyzing the results of the graphical representations in the figure 85, the parameters below are available. Moreover, in the table 29, it is given the association between color of lines & parameters.

- Coolant temperature[85]
  It is visible that the coolant temperature is almost stable, with an amplitude of 5.300, and measured in °C. It is notable that, when the rpm increases, it performs a small variation downwards. The reason is that as the rpm increases, the temperature of the engine increases. Consequently, the temperature of the coolant liquid increases, since it is trying to keep the temperature needed.

[83] Simulink model for a four-stroke, SI engine.
[84] Theoretically, throttle angle and load torque should also be provided.
[85] Measure the temperature of the coolant mix in the cooling system, giving an indication of how much heat the engine is giving off.

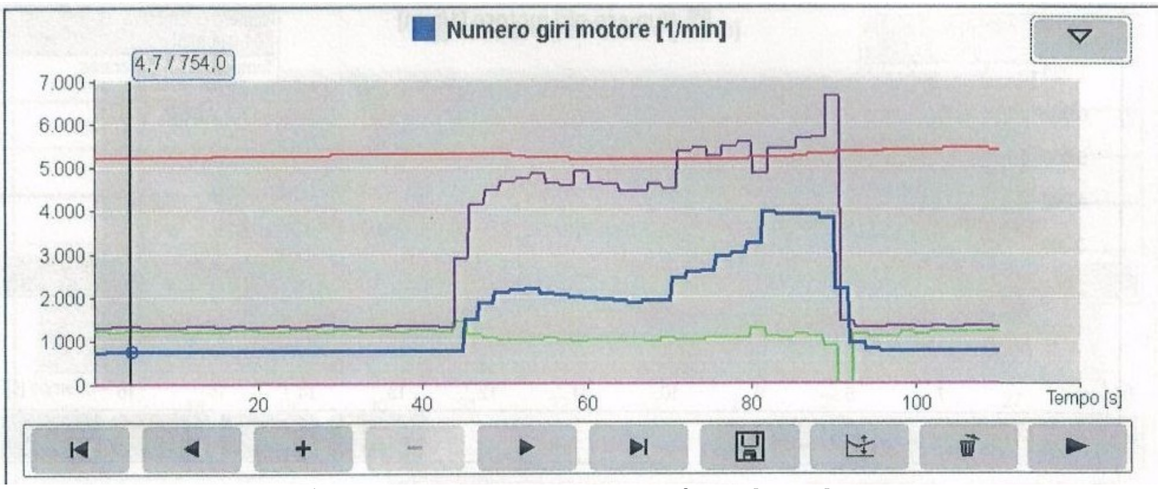


Figure 85: First representation of Bosch results.

- Injection duration[86]
  Its amplitude is around 1.100, and measured in ms. It is obvious that, by increasing the rpm, it performs a small decrease. In the case that the rpm decreases significantly, Injection duration appears a dumping. When the rpm goes to the idle, it regains its original value. The reason is that, when the rpm goes drastically downwards the ECU issues the signal to stop the injection. In this way, the speed of the engine/vehicle can be fast reduced.

- Ignition timing[87]
  Its amplitude is 1.300 ÷ 6.800, and measured in °. Right before the increase of the rpm, the ignition timing curve starts increasing. It is apparent, that it follows the ups and downs of the rpm curve, but it is importantly amplified. The moment that the rpm dicreases drastically, the ignistion timing follows exactly. The fuel does not burn when the spark fires, so it is necessary for the ECU to advance or retard the spark timing. Thus the rotational speed of the engine is able to change the time frame, during which the following are performed:
  - Burning
  - Expansion.

  In this case, there is not retarding nor advancing.

- Retarding ignition timing
  The retarding of the ignition timing for each cylinder is 0°. As mentioned above, there is not retarding of the ignition time, which justifies the zero amplitude.

Color of line	Parameter
Red	Coolant temperature
Green	Injection duration
Blue	Rpm
Violet	Retarding ignition timing
Purple	Ignition timing

Table 29: Association between line color & parameter for the first graph.

[86] *Injection duration* is the period of time during which fuel enters the combustion chamber from the injector

[87] In a spark ignition internal combustion engine, Ignition timing refers to the timing, relative to the current piston position and crankshaft angle, of the release of a spark in the combustion chamber near the end of the compression stroke

2. For representing and analyzing the results of the graphical representations in the figure 86, the parameters below are available. Moreover, in the table 30, it is given the association between color of lines & parameters.

- Coolant temperature
  As analyzed previously, the coolant temperature is almost stable with some small fluctuation. But in this representation, since it is time based and the time analysis is not analytical enough, the coolant temperature is stable.

- Angle of throttle
  Its amplitude reaches 1.100, and it is measured in °. It is obvious that when the angle of the throttle pedal is open, the rpm is increased. Likewise, when the angle of the throttle pedal is closed, then the rpm reaches the idle value. This happens because, the throttle opening is directly linked to the increase or decrease of the engine's speed, since it inserts the air in the engine.

- Injection duration
  As explained before, it is apparent that the moment that the rpm decreases, it reaches zero.

- Ignition timing
  As seen above, since the rpm decreases, the ignition time follows.

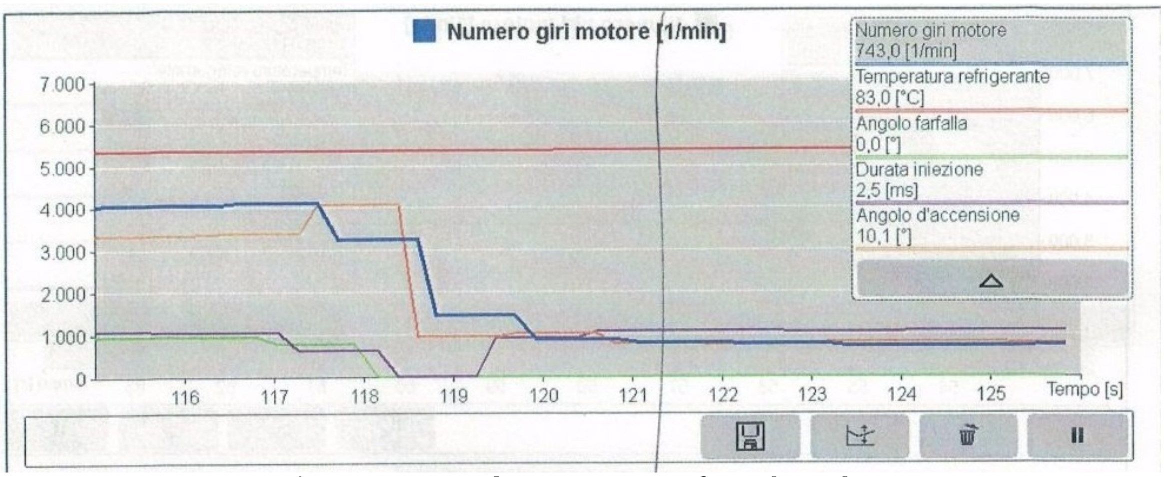


Figure 86: Second representation of Bosch results.

Color of lines	Parameters
Red	Coolant temperature
Blue	Rpm
Orange	Ignition timing
Green	Angle of throttle
Purple	Injection duration

Table 30: Association between line color & parameter for the second graph.

3. For representing and analyzing the results of the graphical representations in the figure 87, the parameters below are available. Moreover, in the table 31, it is given the association between color of lines & parameters.

- Coolant temperature
  As in the other graphs, it performs a small fluctuation, which in this case is visible because the time analysis is detailed enough.

- Intake air temperature
  The amplitude is 3500, and it is measured in °C. It almost keeps its stability with a small increase, which is expected because, as more air inserts, the rpm increases. The engine is already warm and affects the intake air.

- Minimum position of acceleration pedal
  It is obvious that, it gets a default value of amplitude because in this project, the acceleration pedal is not connected.

- Mass of intake air[88]
  It has an amplitude of 1000, and is measured in kg/h. Apparently, it is almost stable with only a small increase during the increase of rpm. And the peak of the curve is at the same time as the peak of the rpm curve. It behaves like this because, with an increase of air, there is an increase of rpm, which means that right after the greatest volume of intake air follows the peak of rpm. Thus when it dicreases, the rmp dicreases as well.

- Angle of throttle
  As explained above, it follows the rpm. When the rpm increases or decreases, it follows but with an offset.

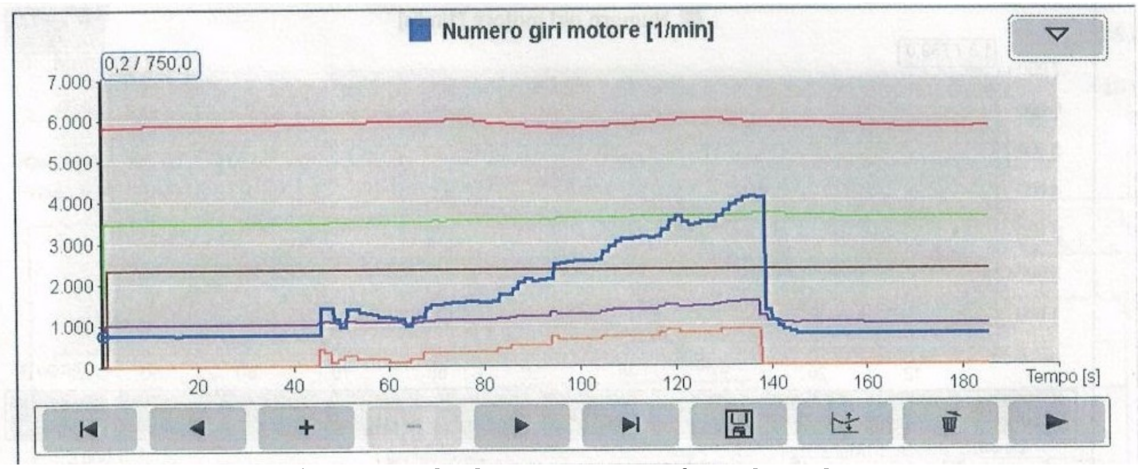


Figure 87: Third representation of Bosch results.

Color of lines	Parameters
Red	Coolant temperature
Green	Intake air temperature
Brown	Minimum position of acceleration pedal
Purple	Mass of intake air
Blue	Rpm
Orange	Angle of throttle

Table 31: Association between line color & parameter for the second graph.

88 Represents the volume of intake air.

10.1.2 The startup of the engine results

The results are obtained , during the first tryouts of the test-bench, while testing[89] each component separately. But also, it is really important to contrast them with the rpm of each experiment. In this way, it will be possible to understand that by the change of rpm, the measured values of the different components change as well. Moreover, it is important to mention that the engine has just started to work and the ECU doesn’t have enough data to control efficiently the engine. Thus, the following measurements of the components are time and rpm dependent.

- Injectors
  In the figure 88, two different testings are illustrated. The two testings are presented to provide the injection time as time & rpm dependent.
  - In the first, it is apparent that the injection is happening during the changing state of rpm, and more specifically it follows the rpm. This example gives the good working condition of the test-bench.
  - In the second, since the rpm fluctuates strongly, then the injection's time is also fluctuating. This example gives the faulty working condition of the test-bench.

- Stepper motor
  In the figure 89, it is obvious that the stepper motor follows the rpm. As long as the:
  - rpm fluctuates, then the stepper motor fluctuates
  - rpm stops, then the stepper motor goes to the idle condition.
- Throttle
  In the figure 90, it is illustrated the rpm changes of the throttle opening. When the rpm stops, then the throttle doesn't close immediately, but with a delay. This delay shows a problem of the test-bench.

- Sparks
  In the figure 91, it is illustrated:
  - First, the wrong behavior of the test-bench, as the spark advance fluctuates in an unstable way, when the rpm fluctuates.
  - Second, a normal behavior of the test-bench. The spark is performed, only when the rpm triggers it.

- Lambda
  Apparently, the lambda does not work properly. The signal is random and not coherent to the rpm, as seen in the figure 92.

[89] The Multiecuscan diagnostics is used for these testings.

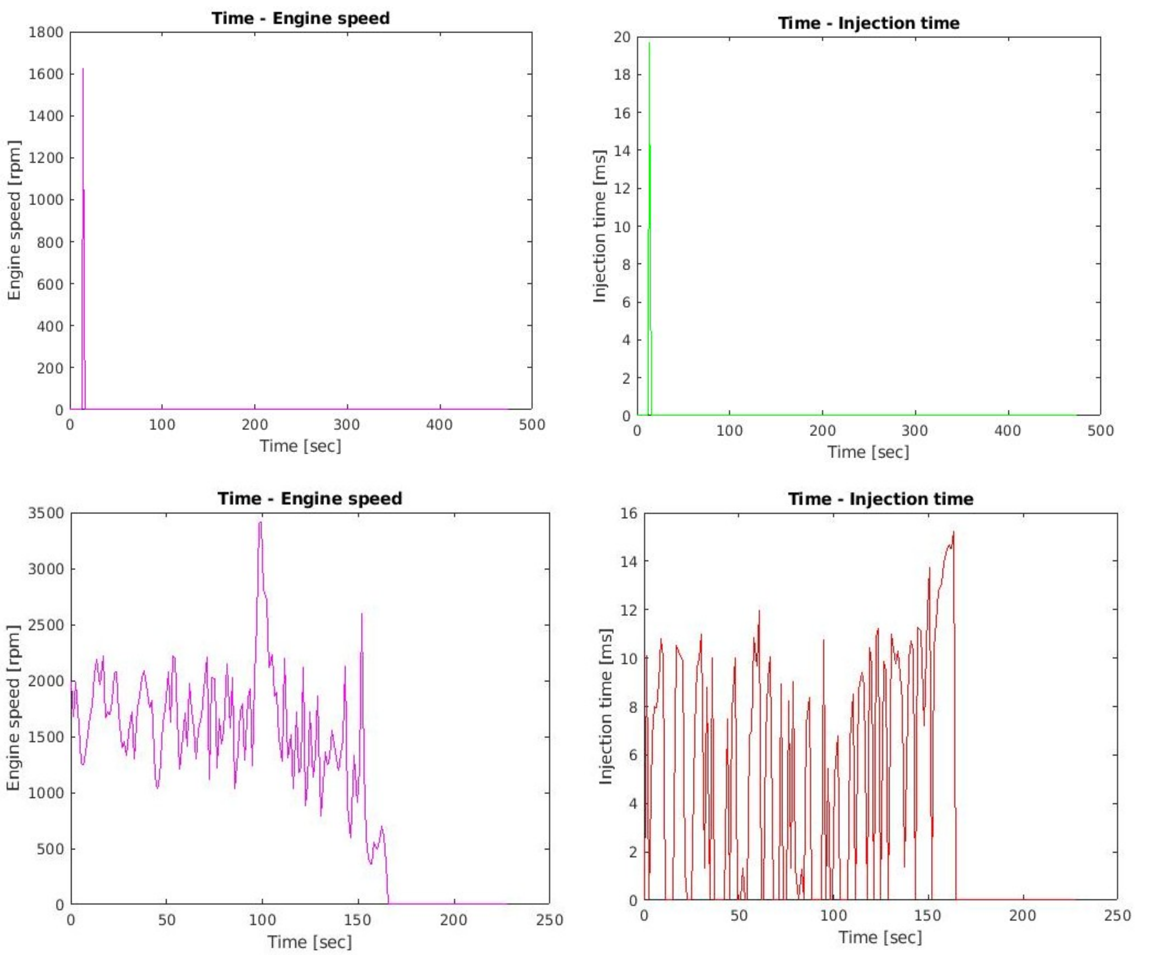


Figure 88: Injection time as rpm & time dependent.

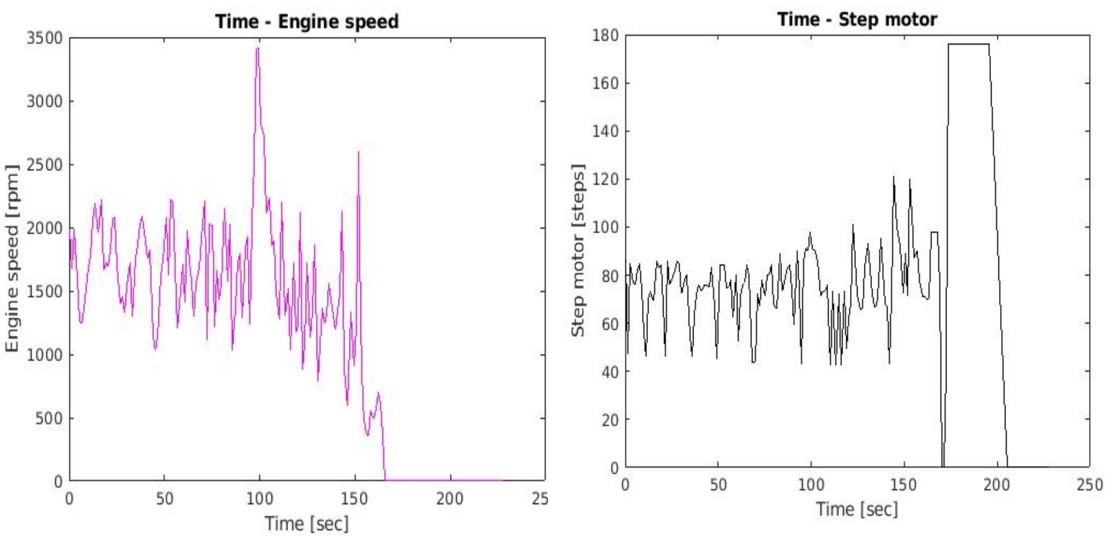


Figure 89: Stepper motor as rpm & time dependent.

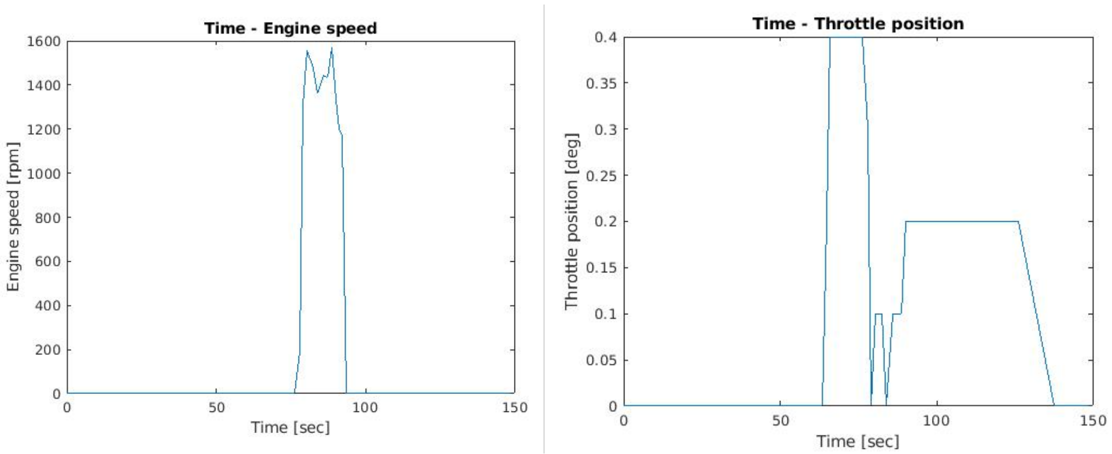


Figure 90: Throttle position as rpm & time dependent.

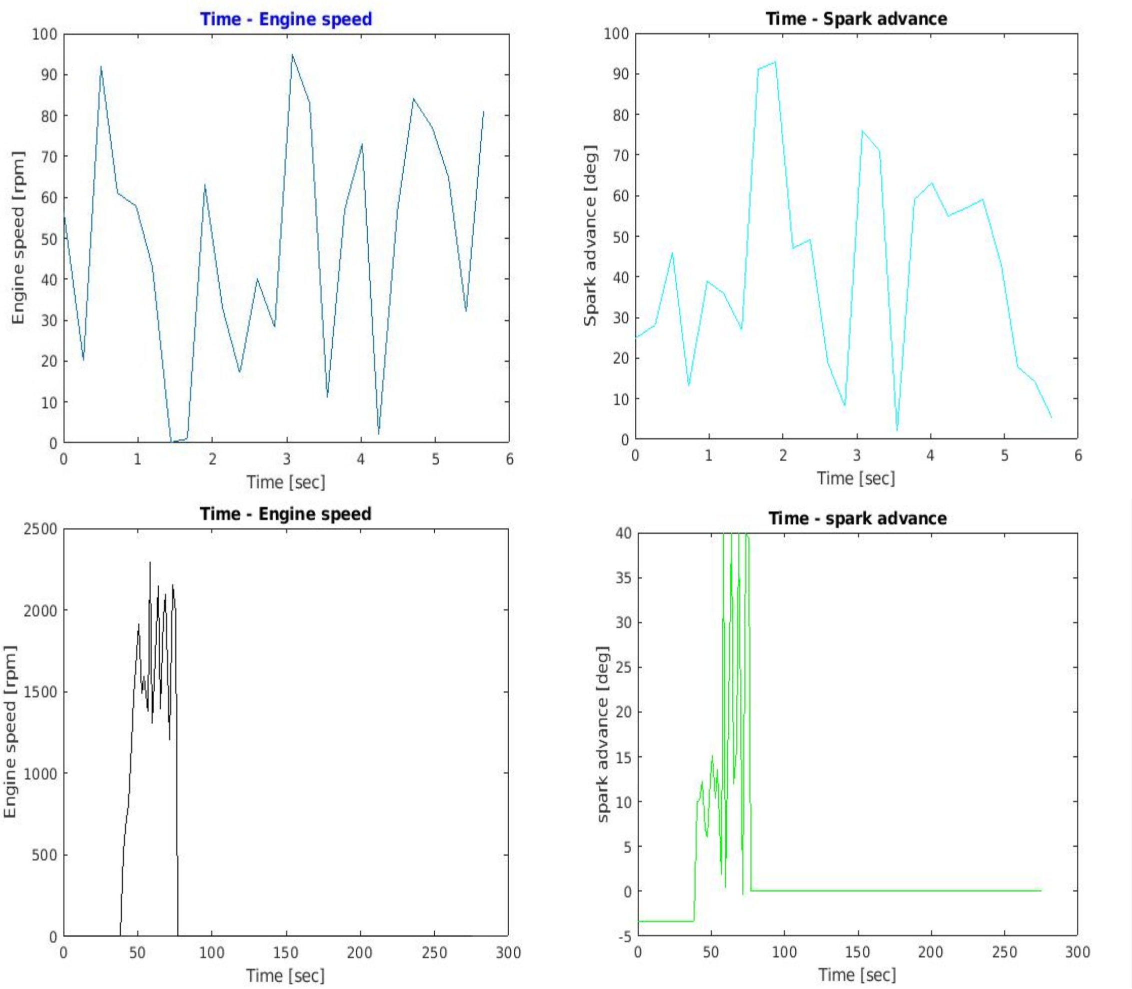


Figure 91: Spark advance as rpm & time dependent.

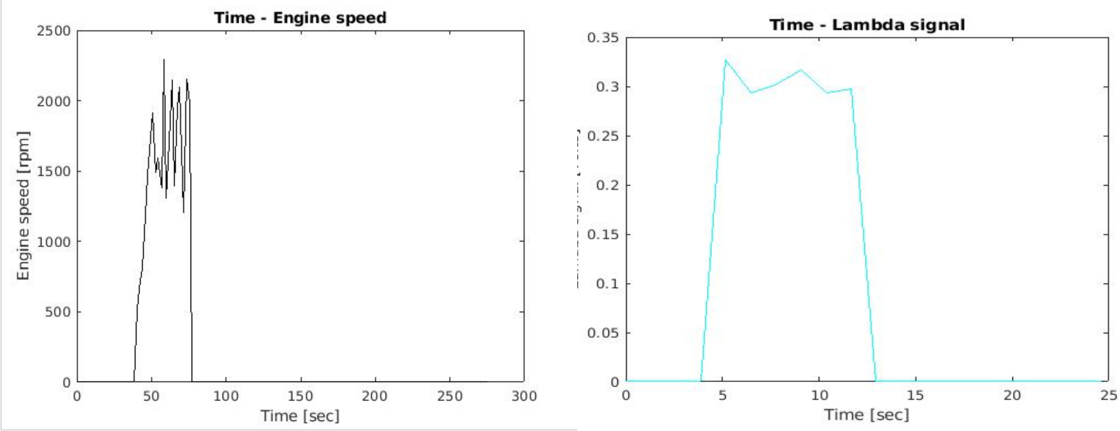


Figure 92: Lambda as rpm & time dependent.

- Knock sensor
  For the knock sensor and from the results in the figure 93[90], it is obvious that in a specific time and rpm, as set in the figure 94, the combustion in three first cylinders, is correct. But the combustion in cylinder 4 is not correct.

[90] In this figure the c1, c2, c3 & c4 refer to the cylinder 1, 2, 3 & 4.

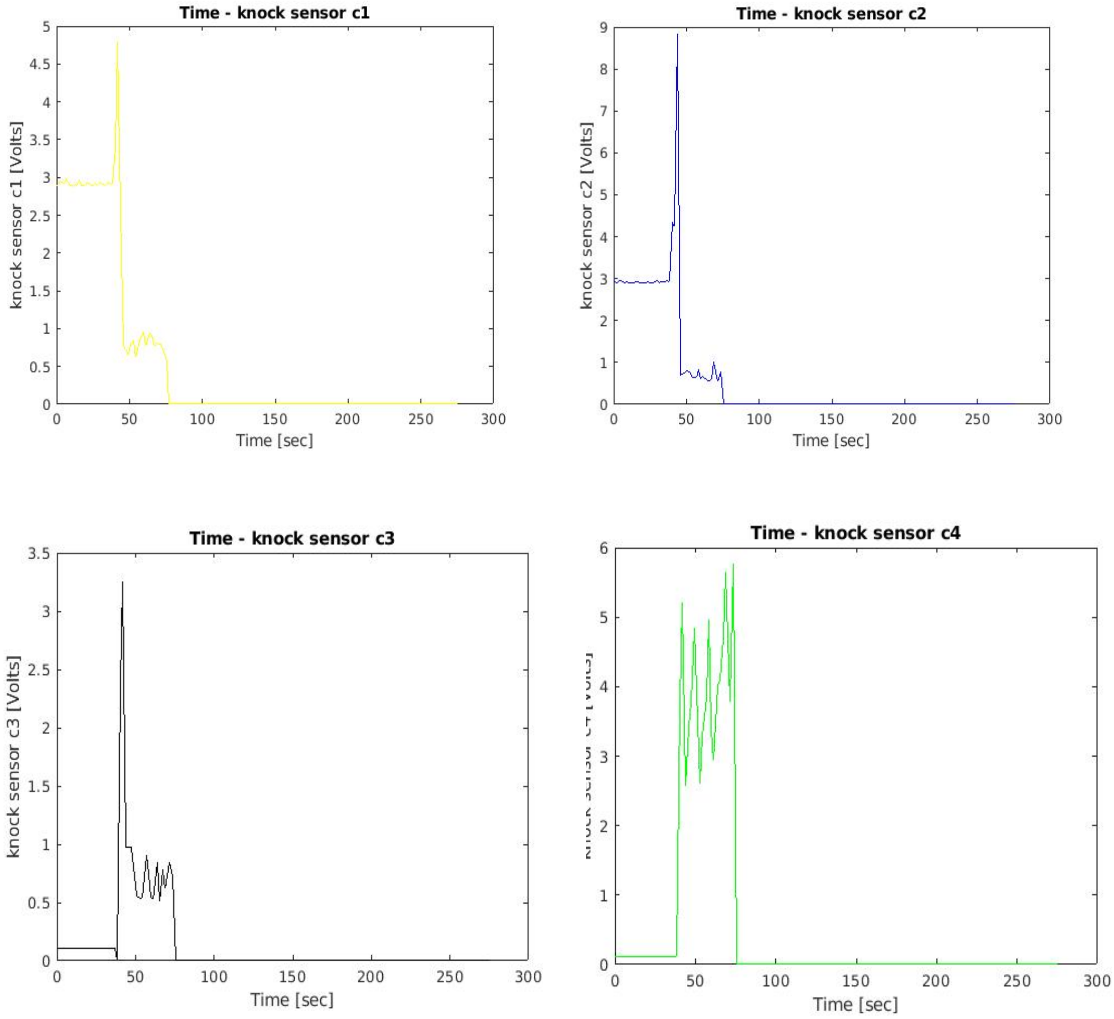


Figure 93: Knock sensor results for all four cylinders.

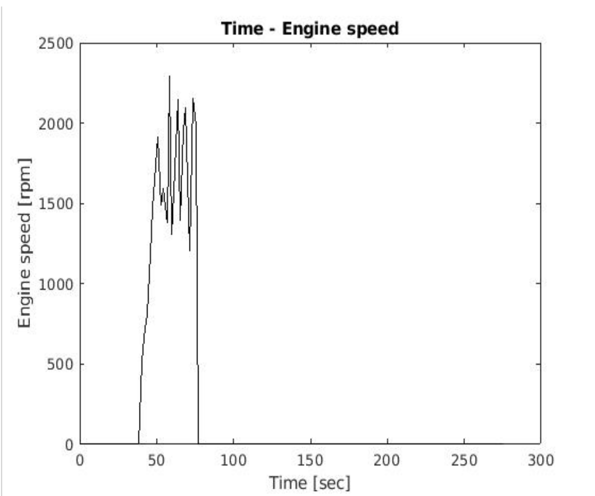


Figure 94: Rpm associated to the knock sensor testing.

- Engine temperature
  In the three following testings, there are presented the following situations in faulty condition, as seen in the figure 95.

  - First, the rpm is increasing, but the temperature starts increasing after a great delay.
  - Second, the rpm is fluctuating and after some time it reaches zero. But the temperature of the engine escalates even after the zero rpm. After a great delay the temperature goes to zero as well.
  - Third, the rpm starts fluctuating, but the temperature is already high and drops to zero even when the rpm keeps fluctuating.

- TDC, absolute pressure & canister
  Due to limited time and funding, these specific sensors are not implemented. Thus, no results available.

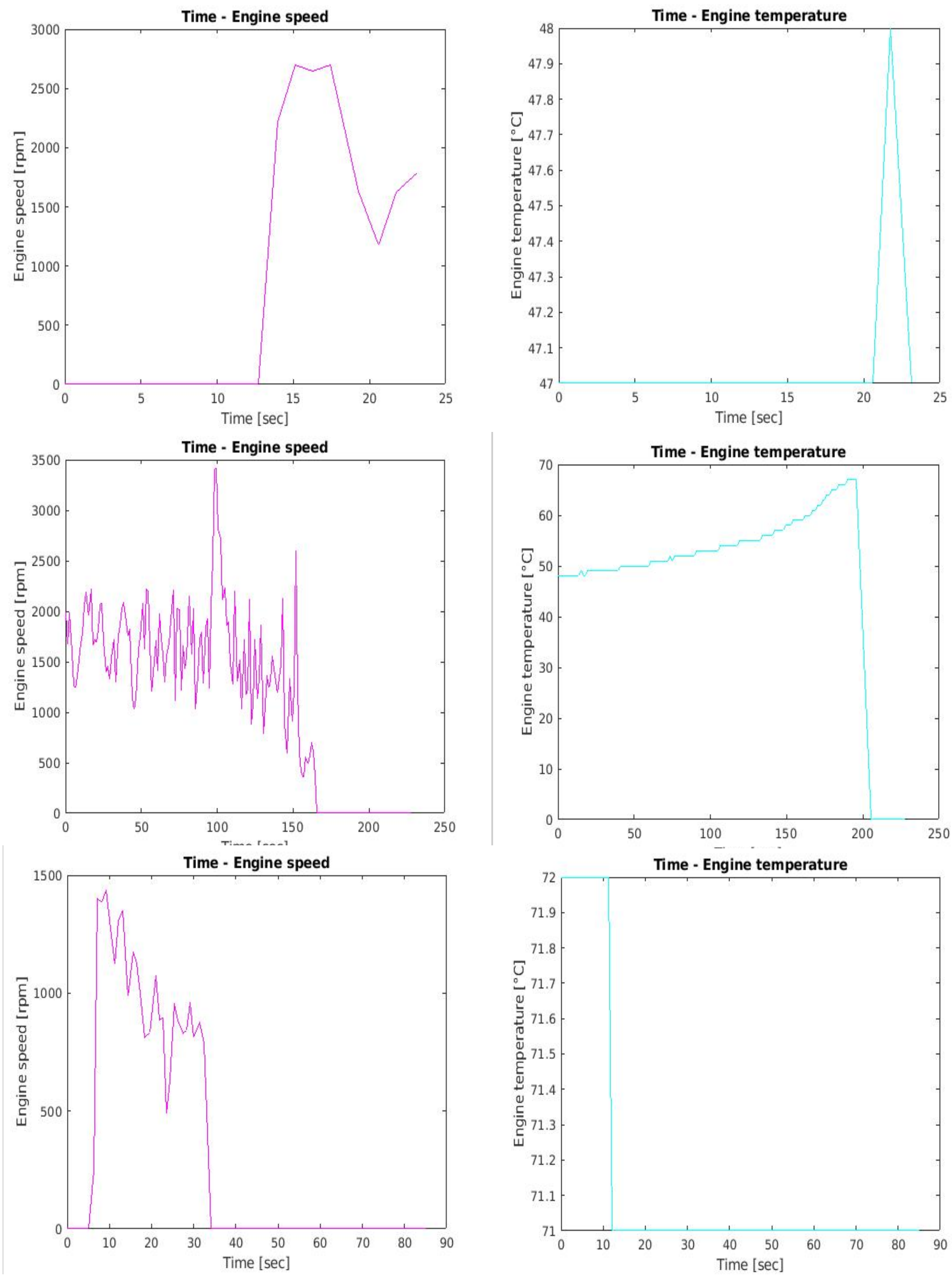


Figure 95: Engine temperature as rpm & time dependent.

10.1.3 Engine working efficiently results

The results are acquired, during the testing[91] of a good working test-bench, while testing each component separately. A contrast with the rpm will be performed once more to understand the analysis, since the triggering for the parameters is the rpm change. In this phase, the ECU has gotten synchronized and is able to control the actuators and:

- read
- and analyze

the data from the sensors. Since the performed testings are many in number, in this analysis only the most important are presented. The changes of the parameters/components are time and rpm dependent. The analysis is going to follow three different testings with several components contrasted.

- First testing
  In the first testing, as seen in the figure 96, it is apparent that the rpm is changing in time, which means that the following components are being triggered:
  - Injection time is fluctuating. Starts when rpm starts and stops when rpm stops.
  - Throttle angle is increasing and decreasing accordingly, with a small delay[92].
  - Engine temperature is increasing once the engine is turned on, and decreasing when:
    - the rpm goes to zero
    - there is no idle
    - the engine off
  - Lambda and Canister are not working. Due to limited time and funding, it is not possible to change them with new ones.

- Second testing
  In the second testing, as given in the figure 97, it is apparent that the rpm is changing in time, which means that the following components are being triggered:
  - Spark advance is approximately following the ups and downs of the rpm. Starts when rpm starts and stops when rpm stops.
  - Spark ignition is representing the signal of spark in coils 1&4, 3&2.
  - Absolute intake pressure is changing in inverse proportion to the throttle opening. When rpm increases, then throttle opening increases and absolute intake pressure decreases.

- Third testing
  In the third testing, as provided in the figure 98, it is apparent that the rpm is changing in time, which means that the stepper motor is changing as well[93]. When the rpm stops the idle starts.

- TDC and knock sensor.
  Due to limited time and funding, these sensors are not implemented. Thus, no results are available.

[91] The Multiecuscan diagnostics is used for this testing.
[92] In this case, it is negligible.
[93] Following the rpm.

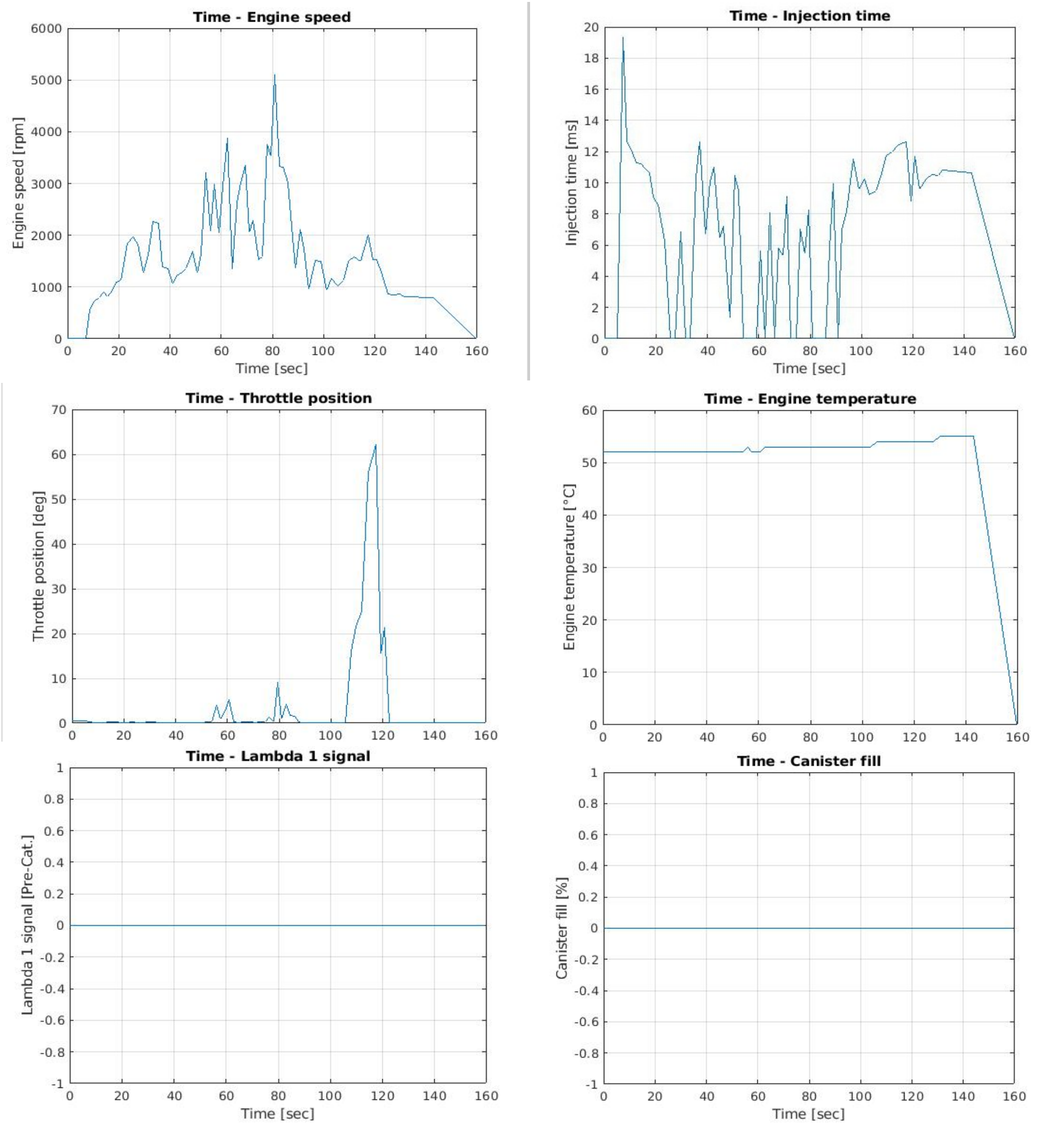


Figure 96: First testing of a good working engine.

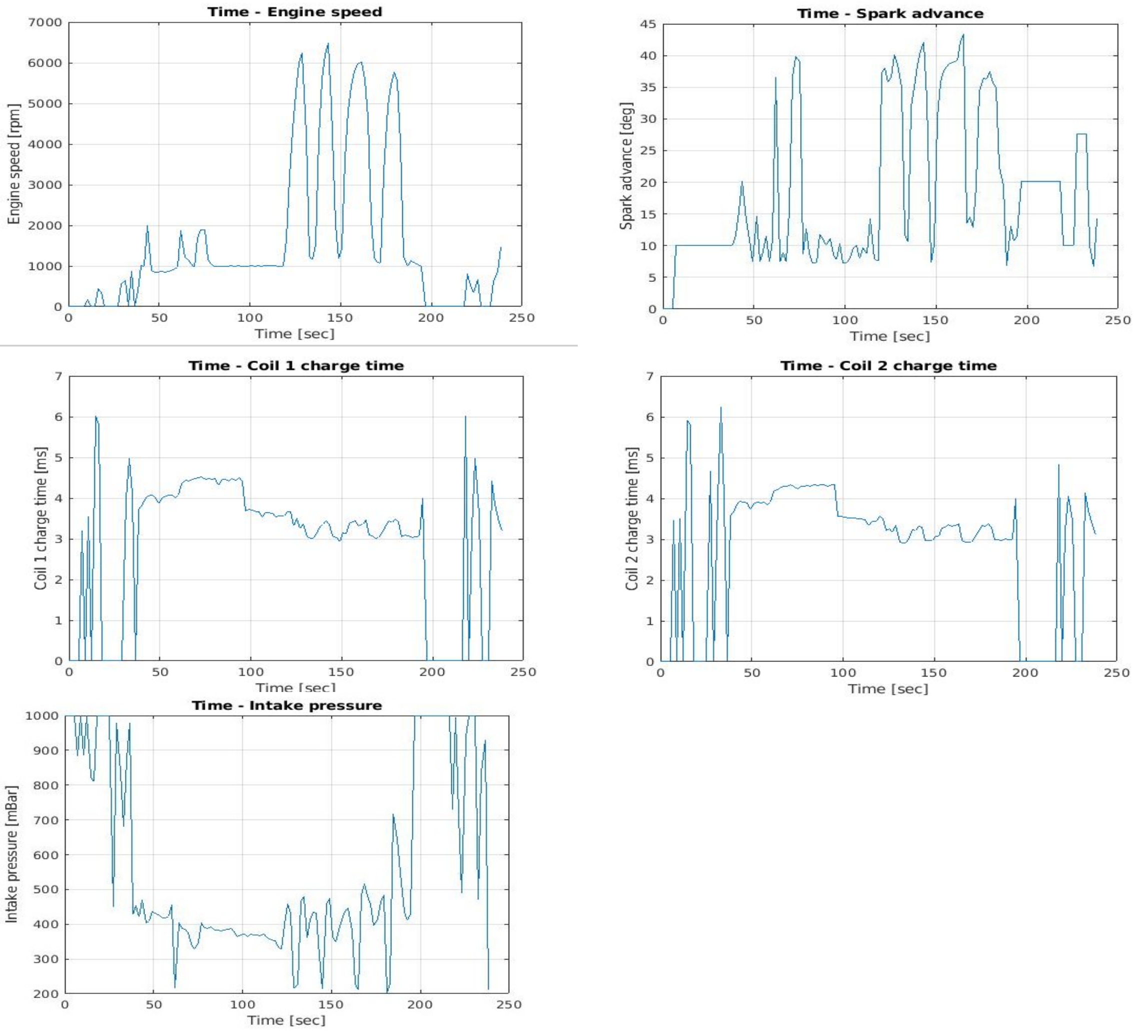


Figure 97: Second testing of a good working engine.

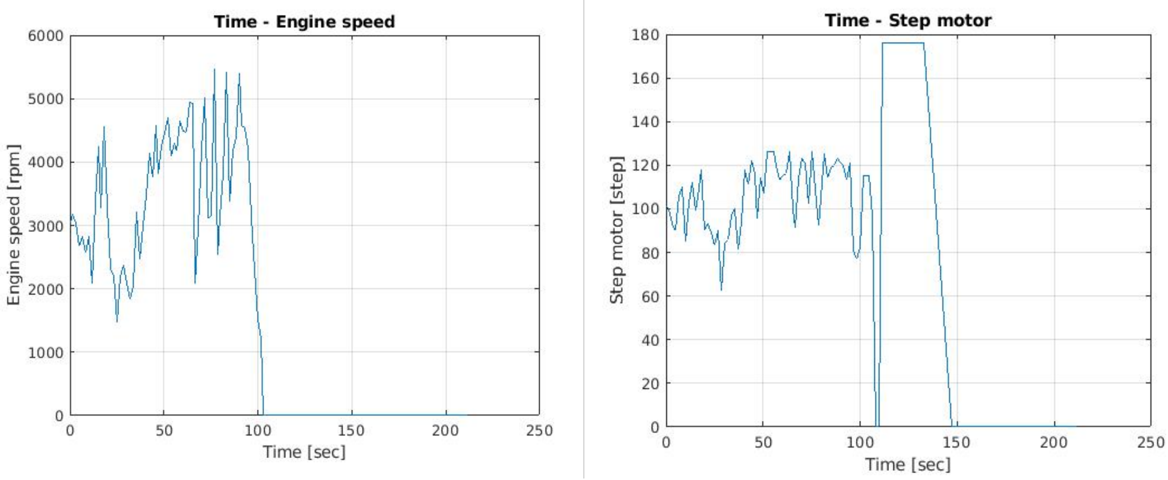


Figure 98: Third testing of a good working engine.

10.1.4 Simulink model result

The simulink mathematical model of an SI four-stroke engine, which is presented in the chapter 2, provides this project with an output signal, which is illustrated in the figure 99. The simulation gives outcomes for the engine and not for the test-bench[94]. The outcomes give information about the:

- rpm
- and smooth correction of the signal.

As a result, this testing presents outcomes from rpm control.

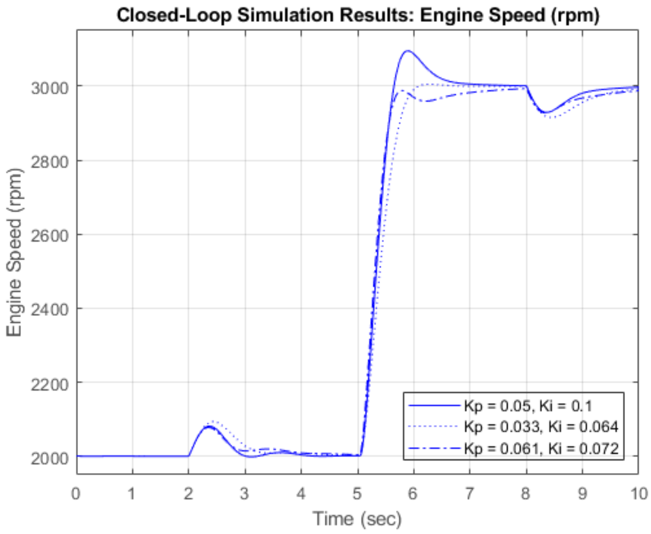


Figure 99: Output signal plot of the simulink model.

10.2 Comparison

In this sub-chapter, the reference signals of all the components, which are provided in the chapter 7, will be compared with:

- the Bosch
- and Multiecuscan

diagnostics results[95].

On the other hand, the result of the simulink model of the engine cannot be compared to the reference signals. This happens because the reference signals provide outcomes that give information about the condition of the engine, but the simulink model provides an example of smoothing the curve[96] of the rpm.

10.2.1 Comparison with Bosch diagnostics results

By comparing the reference signals with the results of the Bosch diagnostics, which are presented in the sub-chapter 10.1.1, it is visible that they cannot be compared as component by component but as concept. This means that based on the:

- theory

[94] Refers to the whole system, with all its components.
[95] Both faulty & good working conditions.
[96] Refers to control of rpm.

- and explanation

in this report, then the parameter results:

- are logically correct
- and prove the good working condition of the engine.

10.2.2 Comparison with Multiecuscan diagnostics startup results

By comparing the reference signals with the results of the Multiecuscan diagnostics during startup, which are presented in the sub-chapter 10.1.2, it is visible that they can be exactly compared as component by component. As a consequence, based on the:

- theory
- explanation
- and reference signals,

the comparison gives the information that the engine is not synchronized, thus it is not working efficiently.

10.2.3 Comparison with Multiecuscan diagnostics working efficiently results

By comparing the reference signals with the results of the Multiecuscan diagnostics in good working condition, which are presented in the sub-chapter 10.1.3, it is visible that they can be exactly compared as component by component. As a consequence, based on the:

- theory
- explanation
- and reference signals,

the comparison gives the information that the engine is synchronized, and working efficiently.

Chapter 11 Conclusions and future work

In this chapter, there are presented the following:

- Future work
  The intention is to substitute gradually and completely the ECU with the arduino. One important advantage is, that with the arduino there are many ways to store the data, since it can be connected to different softwares. The first sensor to try is selected to be the rpm sensor. In this way, it will be easy to understand this specific implementation and if successful, it can lead to expansion for all the instrumentation and actuators for this project. Unfortunately, due to limited time and funding, this part of the project stopped at the need of an electronic circuit for reducing the output voltage of the sensor.

- Conclusions
  In this sub-chapter, it will be included the conclusions of the whole test-bench report.

11.1 Test of the rpm sensor

The goal is to create a small testing procedure to simulate the rpm sensor and the data aquisition of it. The main components that are needed are the :

- generator to supply the DC motor
- DC motor with a rotating wheel in the form of 3 teeth[97]
- rpm sensor
- oscilloscope
- arduino[98]

The main component that needs to be studied is the rpm sensor, as seen in the figure 100. After studying and comparing it is decided that the type of the sensor is magnetic inductive[99] sensor. The internal resistance of this sensor, is verified and measured to be equal to 927Ω. At this point, it is important to check the performance of the sensor with the help of an oscilloscope, as seen as an example in the figure 101.

Figure 100: Rpm sensor for future work.

97 Simulation of a phonic wheel.
98 Hardware & software.
99 Crank

The output signal of a magnetic inductive sensor, must be an AC sinusoidal voltage. The AC voltage value is proportional to the speed of the wheel. But the most important element is the measurement of the frequency. The rpm value is provided by the frequency.

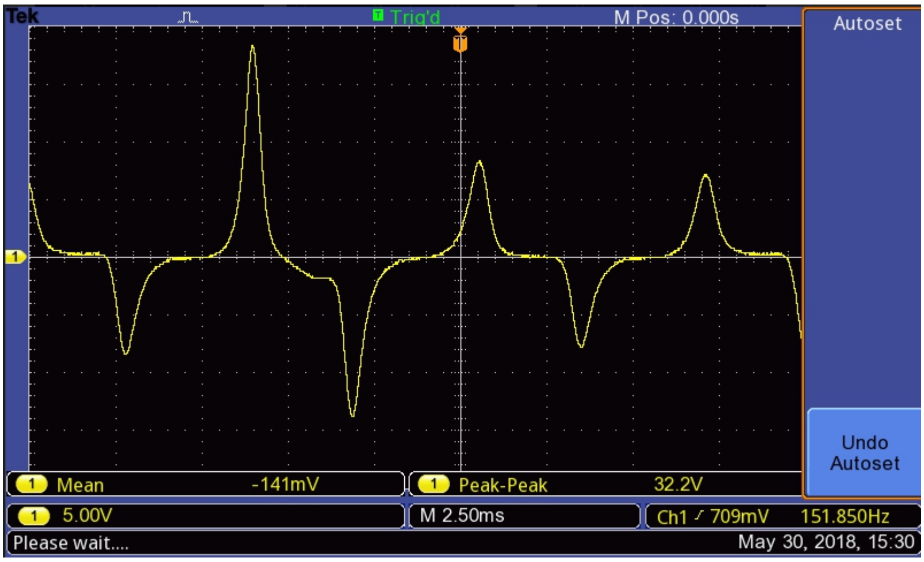


Figure 101: Example of the oscilloscope screen.

In the table 32, it is performed the measurement testing for verifying the highest value of AC voltage that the output may give.

Steps	Supply voltage	Output Current	Frequency measured
1	1V	1.37A	10Hz
2	1.5V	1.37A	20Hz
3	2V	1.46A	11Hz
4	2.5V	1.46A	28Hz
5	3V	1.46A	53Hz
6	3.5V	1.46A	61Hz
7	4V	1.5A	69Hz
8	4.5V	1.5A	82Hz
9	5V	1.56A	92Hz
10	5.5V	1.56A	101Hz
11	6V	1.65A	112Hz
12	6.5V	1.65A	120Hz
13	7V	1.7A	134Hz
14	7.5V	1.71A	142Hz
15	8V	1.78A	152Hz

Table 32: Measurement of the rpm sensor.

For the testing procedure, it is decided to increase the voltage every 0.5V, because the changes are not big enough to support more testing points.

The next part is to integrate it with Arduino, so that it will be able to read the output[100], and calculate the rpm value. For this reason, an electronic circuit should be built, with which the output voltage will be reduced to the range of 0V ÷ 5V[101]. The proposed electronic circuit is an « instrumentation amplifier ».

The procedure below is followed to store and plot the frequency duration data of the teeth of the rotating wheel.

I. Code for measuring the duration of the frequency.

Code :

```
volatile int16_t pwm = 0; //pwm value
volatile int16_t trig = 0; //timer value
float freq;
long duration;
#define pin 2 //pin the interrupt is attached to

void intHandler() //function to call on interrupt
{
   if(digitalRead(pin)) //if the pin is low to HIGH, note the time
  {
   trig = micros();
  }
  else
  {
   pwm = micros()-trig; //if it is high to low, end the time
  }
}

void setup(){
  pinMode(pin, INPUT); //set the pin to input
   attachInterrupt(0,intHandler,CHANGE); //attach the interrupt function "intHandler" to
"pin" whenever the state changes
  pinMode (9, OUTPUT);
  Serial.begin(9600); //begin serial comms
  //TCCR1B = TCCR1B & B11111000 | B00000101; // for PWM frequency of 30.64 Hz
  //TCCR1B = TCCR1B & B11111000 | B00000010; // for PWM frequency of 3921.16 Hz
   TCCR1B = TCCR1B & B11111000 | B00000001; // set timer 1 divisor to 1 for PWM
frequency of 31372.55 Hz
}
```

II. Code for printing the data. In the figure 102, it is illustrated an example codefor this reason.

100 Voltage & frequency.
101 It is the range that arduino can read.

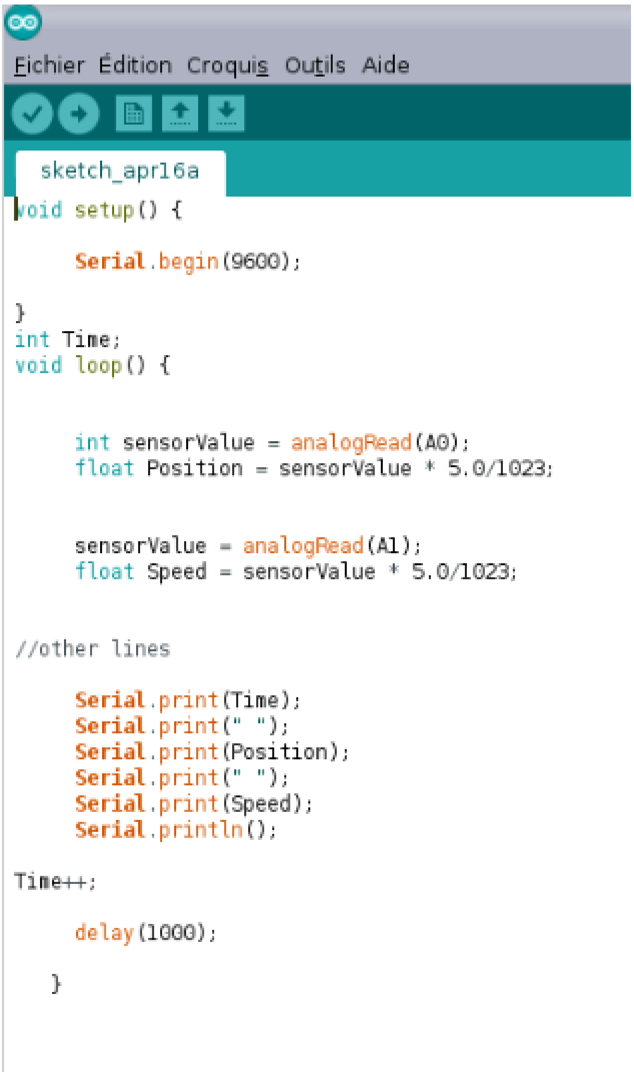


Figure 102: Example code for printing data.

III. Code for python to read and store the data in a text file. In the figure 103, it is presented an example code for this purpose.

```python
import serial

ser=serial.Serial("/dev/ttyACM0", 9600)
f = open('helloworld.txt','w')
f.write("time(s) position(s) speed(s)")

count=0
while (count < 51):
        something = ser.readline()
        print something
        f.write(something)
        count=count+1

f.close()
```

Figure 103: Example code for storing data in a text file.

11.2 Conclusion

In this sub-chapter, it is included the conclusion of the whole report, in which it is provided the:

- statement of the purpose and the proposed method to use for this project.
- theoretical explanation of the most important components and specifications of the engine and test-bench, for understanding its functionality.
- design and fabrication of the components that are designed and provided only in this report.
- analytical analysis of the instrumentation and actuators, which are used for the test-bench.
- calibration, which is focused on the reference signals of the components used and the ECU self-adaptation.
- testing procedure with its every testing step that is followed.
- data processing, for explaining which exactly is the procedure followed for the data acquisition.
- analysis of the results, for understanding the condition of the engine in every state
- future work project, for substitution of the ECU.

By collecting all the previous, it is obvious that this project is developed in well organized and strategically structured steps. At first, the theoretical training is taking place. After the method strategy is defined, in order for estimating the work needed. As the project is being developed, the:
*design
*calibration
*and testing procedure,
are establishing and modifying the already existing method on line[102].
Finally, data acquisition and analysis complete this project. In addition, the future work prepares the next steps for the expansion of this project.

[102] means that the method is being modified as it is evolving.

APPENDIX A: BIBLIOGRAPHICAL REFERENCES

[1] Atkins, R.D. An Introduction to Engine Testing and Development. 2009

[2] Crossley, P.R., Cook, J.A. A nonlinear engine model for drivetrain system development. 1991.

[3] Matlab documentation. Modeling Engine Timing Using Triggered Subsystems. www.mathworks.com

[4] Simulink Model. Developed by Ken Butts, Ford Motor Company. www.mathworks.com. 1994-7

[5] Moskwa J.J., Hedrick J. K. Automotive Engine Modeling for Real Time Control Application. 1987

[6] Powell B. K., Cook J. A. Nonlinear Low Frequency Phenomenological Engine Modeling and Analysis. 1987

[7] Weeks R. W., Moskwa J. J. Automotive Engine Modeling for Real-Time Control Using Matlab/ Simulink. 1995

[8] Kaloudiotis E. A 169 MHz and 868 MHz Wireless M-Bus Based Water and Electricity Metering System. 2015

[9] OBD Diagnostics. Pre-Check. www.wlap.org. 2016

[10] OBD-II. Check Engine Light Trouble Codes. www.obd-codes.com. Obd-codes.com. 2016

[11] Vigild C. W. The internal combustion engine. 2001

[12] Wiseman M. W. Spark ignition engine combustion process analysis. 1990

[13] Johansen L. C. R. Spark Ignition Combustion of Direct Injected Alternative Fuels. 2016

[14] Wagner R. C. Four-Stroke, Internal Combustion Engine Performance Modeling. 2017

[15] Grobbelaar E. The Development of a Small Diesel Engine Test Bench Employing an Electric Dynamometer. 2017

[16] Oldenkamp A., O., Skene-Hamilton C., Egilson K. Design of an engine test stand : design report. 2012

[17] Lee J. A Study on Performance and Emissions of a 4-stroke IC Engine Operating on Landfill Gas with the Addition of H2, CO and Syngas. 2010

[18] Khassaf F. H. The breathing of four stroke internal combustion engines. 1999

[19] Marcin S., Ambrozik A., Jankowski A., Wojciechowski A. Mathematical model of four-stroke combustion engine working process. 2007

[20] Fiat Bravo/a Service Manual Volume 1 & 2. www.fiat-bg.com. 2006

[21] Cirillo 188, youtuber. www.youtube.com.

[22] Easy-run, company. www.easy-run.net.

[23] Arduino programming notebook – Arduino playground. Playground.arduino.cc. 2007

[24] Help – Multiecuscan – Diagnostics software for italian cars. www.multiecuscan.net

[25] Tech 2 – Bosch Diagnostics. www.boschdiagnostics.com

[26] Beurms J. Test bench for a high speed permanent magnet machine. 2014

[27] Mäkelä T., Senou D. Motor test bench designing for the Rotax 912 ULS motor. 2009

[28] Johnsson R. Crankshaft speed measurements and analysis for control and diagnostics of diesel engines. 2001

[29] Pezouvanis A. Engine modelling for virtual mapping. 2009

[30] Hawkins J. Analysis of a Wind Turbine Test Bench Calibration Stand Using the Finite Element Method and Experimental Data. 2014

[31] Santos E. A., Alves W. F., Prado A. N. A., Martins C. A. Development of test stand for experimental investigation of chemical and physical phenomena in Liquid Rocket Engine. 2011

[32] Carpenter M. H., Ramos J. I. Mathematical spark-ignition modeling engines. 1984

[33] Induction Motor Speed Torque Characteristics. www.yaskawa.com. 2006

[34] Killedar, J. S. Dynamometer - Theory and Application to Engine Testing. 2012

[35] Heywood, J. B. Internal Combustion Engine Fundamentals. 1988

[36] Blair, G. P. Design and Simulation of Four-Stroke Engines. 1999.

[37] Annand, W. J. D. Heat Transfer in the Cylinders of Reciprocating Internal Combustion Engines. 1963

[38] Balistrou M., Loubar K., Lounici M. S., Tazerout, M. Investigation on heat transfer evaluation for a more efficient two-zone combustion model in the case of natural gas SI engines. 2010

[39] Baranescu R., Challen, B. Diesel Engine Reference Book. Second Edition. 1999

[40] Bueno A. V., Velásquez J. A., Milanez L. F. Internal Combustion Engine Indicating Measurements. 2012

[41] Dynamometer Engine Testing. www.pcc-sterling.com. 2011

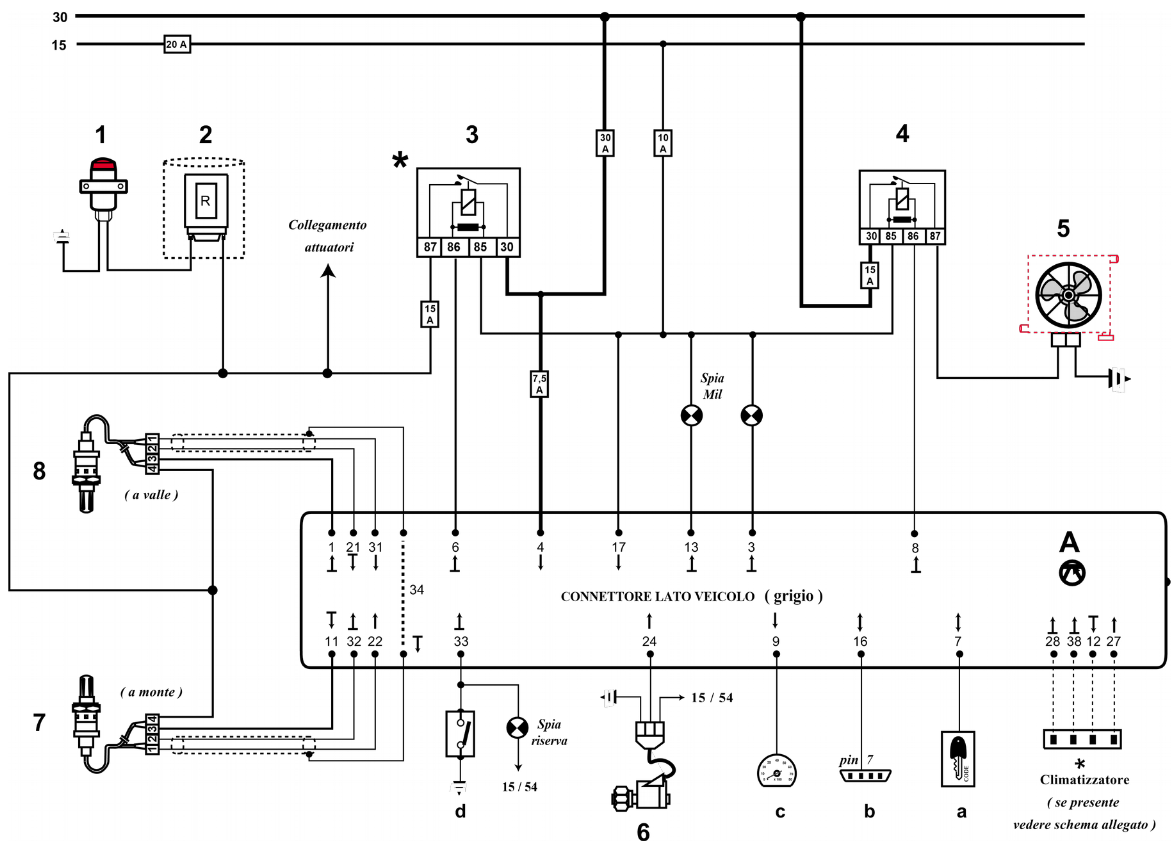
[42] Engine Combustion Analysis. www.kistler.com. 2012

[43] Engine Combustion Modelling. www.me.ua.edu. 2013

[44] Engine Testing Overview. www.sussex.ac.uk. 2013

[45] Ahmadi-Befrui B., Gosman A. D., Lockwood F. C., Watkins A. P. Multidimensional calculation of combustion in an idealized homogeneous charge engine: a progress report. 1981

APPENDIX B: GUIDANCE DOCUMENTATION



LEGENDA A

A) Centralina iniezione 38 pin ***(connettore A) (vedere disposizione componenti)***

1) Interruttore inerziale ***(sotto il sedile del guidatore sul lato sinistro)***

2) Elettropompa carburante con regolatore di pressione e filtro carburante ***(all'interno serbatoio)***

3) Relè principale ***(vedere disposizione componenti)***

4) Relè comando elettroventilatore

5) Elettroventilatore raffreddamento motore

6) Sensore di velocità ***(da tachimetro)***

7) Sonda LAmbda ***(a monte)***

8) Sonda LAmbda ***(a valle)***

a) Collegamento all'antifurto ***(code)***

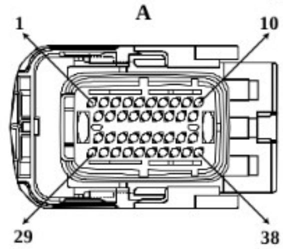
b) Collegamento alla presa diagnosi ***(pin 7)***

c) Collegamento al contagiri

d) Collegamento all'interruttore livello carburante

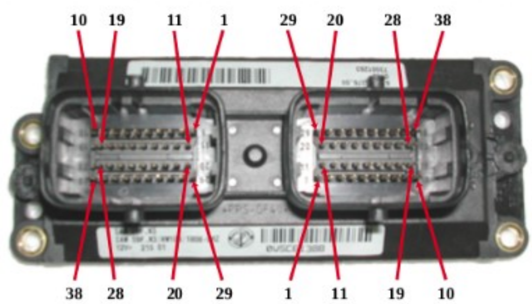
Fusibile elettrovalvola radiatore (nel vano motore)

Fusibile sonda Lambda, elettropompa carburante e Code nella scatola portafusibili nel vano motore lato guida

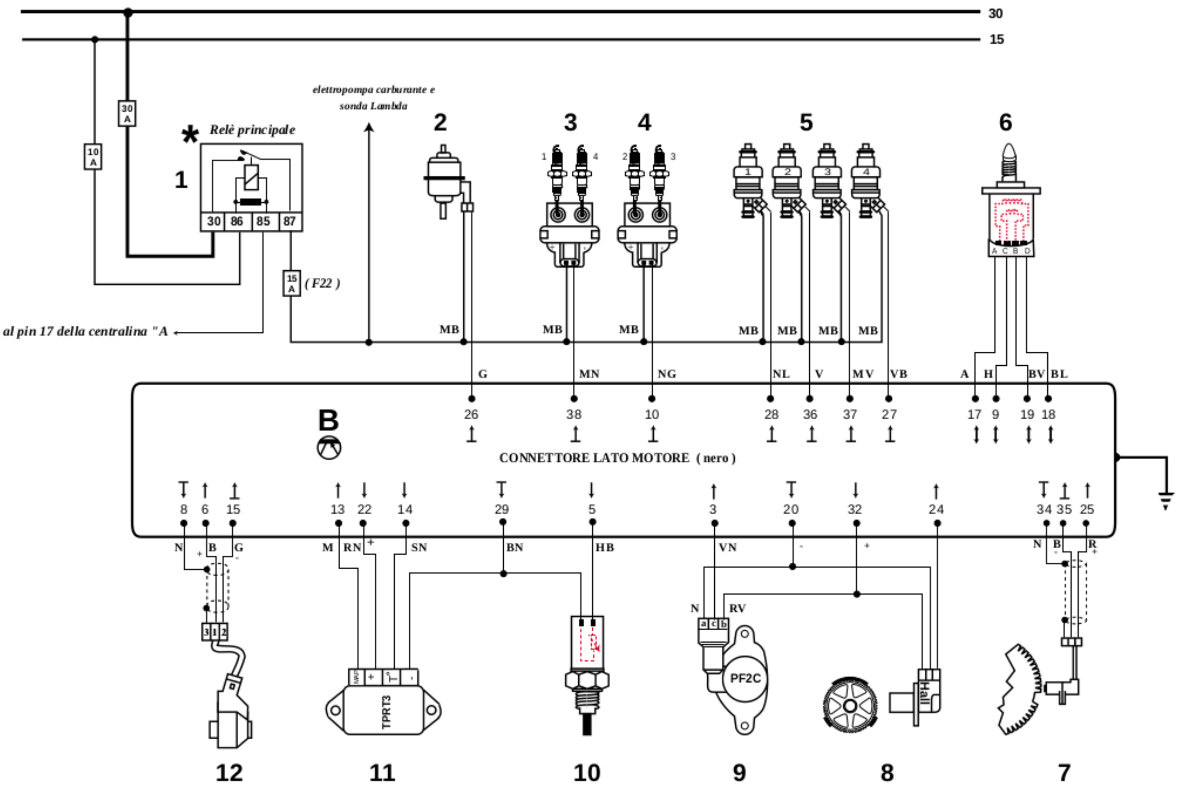


CENTRALINA

CONNETTORE LATO VEICOLO / CONNETTORE LATO MOTORE



Codice colori:
N: nero
R: rosso
V: verde
H: grigio
B: bianco
Z: viola
L: blu
A: azzurro
M: marrone
G: giallo
C: celeste



LEGENDA B

B) Centralina iniezione 38 pin *(connettore B)*

1) Relè principale *(vedere disposizione componenti)*

2) Elettrovalvola vapori benzina *(canister)*

3) Bobina d'accensione *(cil 1 - 4)*

4) Bobina d'accensione *(cil 2 - 3)*

5) Elettroiniettori

6) Motorino del minimo

7) Sensore di giri / P.M.S.

8) Sensore di fase *(hall)*

9) Potenziometro acceleratore

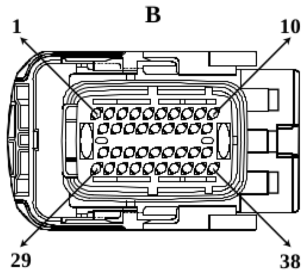
10) Sensore temperatura motore

11) Sensore pressione assoluta / temperatura aria

12) Sensore di battito

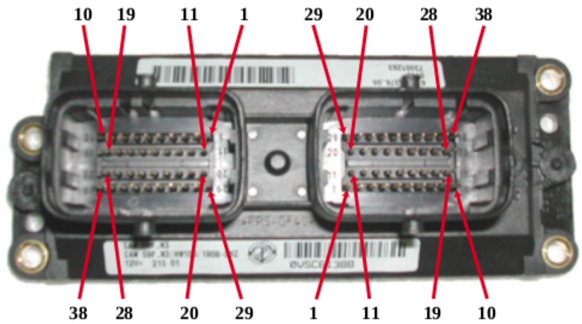
Codice colori:
N: nero
R: rosso
V: verde
H: grigio
B: bianco
Z: viola
L: blu
A: azzurro
M: marrone
G: giallo

SPINA CENTRALINA LATO MOTORE (nero)

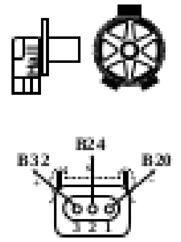
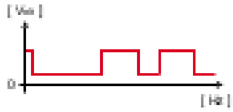
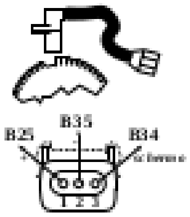
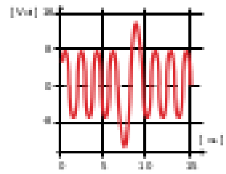
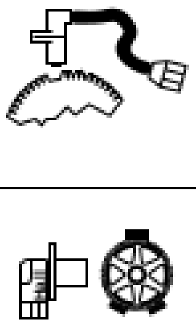
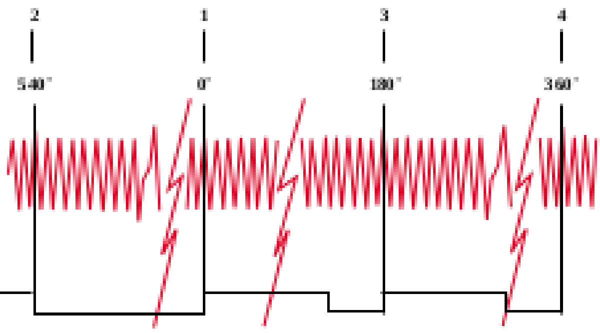
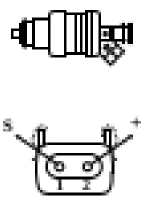
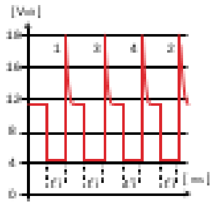
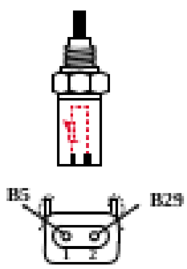
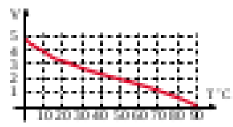


CENTRALINA

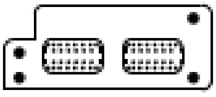
CONNETTORE LATO VEICOLO / CONNETTORE LATO MOTORE

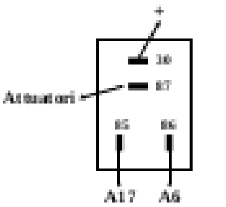
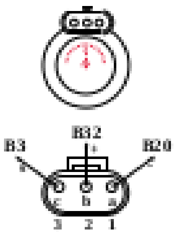
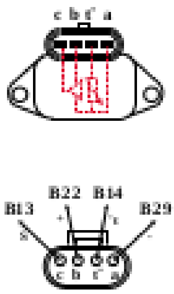
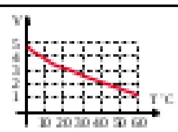


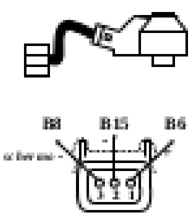
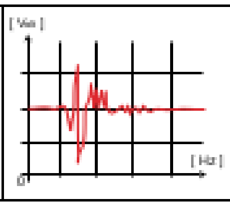
MISURA	CHIAVE	PIN CONNETT. CENTRALINA		OPERAZIONI DI CONTROLLO (su spina scollegata)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
(N. B. CHIAVE DISINSERITA/ASPETTARE 5 MINUTI E SCOLLEGARE SPINE CENTRALINA)					
SPINA LATO VETTURA A (grigio)					
Volt	Stop	⏚	4	**Tensione** permanente	**10 ÷ 15 Volt**
Volt	Mar	⏚	17	**Tensione** a chiave inserita	**10 ÷ 15 Volt**
Volt	Mar		6 a ⏚	**Controllo** comando relé principale alimentazione: elettropompa e attuatori: elettroiniettori, bobine A.T., riscaldamento sonda lambda, elettrovalvola intercettatore vapori benzina *(canister)* *(collegare pin 6 a massa)*	*(rotazione elettropompa)* *(tensione su attuatori)* **10 ÷ 15 Volt**
N.B. **Considerando la difficoltà di operare su spina connettore centralina** **_ per controllo pressione carburante** *(Palio: contenitore vano motore)* **_ per controllo tensione su attuatori,** **ponticellare i terminali del relè con fusibile intermedio i term 30 con 87** *(contenitore vano motore)*					
	Mar		8 a ⏚	**Controllo** comando relé elettroventilatore (97°C) *(1ª velocità)* *(collegare pin 8 a massa)*	*(rotazione elettroventilatore)*
	Mar		18 a ⏚	**Controllo** comando relé elettroventilatore *(se presente)* *(2ª velocità)* (102°C) *(collegare pin 18 a massa)*	*(rotazione elettroventilatore)*
Volt	Mar	⏚	27	**Segnale** inserimento condizionatore *(se presente)*	**10 ÷ 15 Volt**
	Mar		12 ad ⏚	**Controllo** comando relé compressore condiz. *(se presente)* *(collegare pin 12 ad intervalli a massa)*	*(prova uditiva)* *(chiusura frizione compressore)*
	Mar		3 a ⏚	**Controllo** spia max temperatura acqua *(collegare pin 3 a massa)*	*(illuminazione spia)*
	Mar		13 a ⏚	**Controllo** spia avaria *(Mil)* *(collegare pin 13 a massa)*	*(illuminazione spia)*

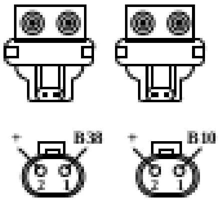
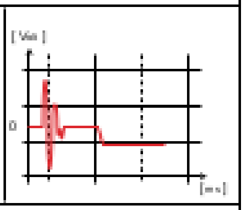
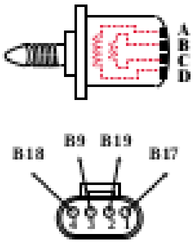
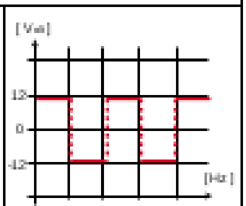
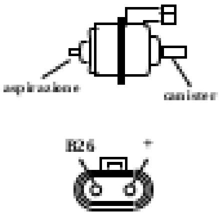
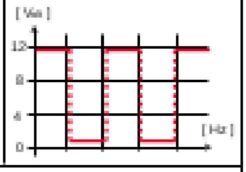
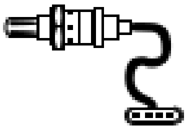
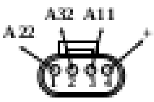
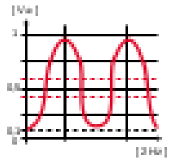
COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA		TERM. CONNETT. COMPONEN.		OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
						**Sensore di fase**	
	Mar	+ B 32	- B 20	+ 3	- 1	**Tensione alimentazione**	**4.8 ÷ 5 Volt**
	Moto	s B 24	- B 20	- 1	s 2	**Segnale** *(3 rilievi su puleggia= 1 largo e 2 medi)* *(motore al minimo 2.5 Volt)*	
						**Sensore di giri / P.M.S.**	
	Moto	+ B 25	- B 34	+ 1	- 2	**Segnale** *(ruota fonica 60 - 2)*	
						**Sincronizzazione segnali in centralina** **PMS cilindri** **Angoli albero motore** **Segnale ruota fonica** **Sensore di fase**	
						**Elettroiniettori**	
	Moto	⏚	B28	1	2	*Cil 1* **Segnale** comando	
			B36			*Cil 2* *(In fase di avviamento vengono comandati contemporaneamente per 5 sec. "full-group")*	
			B37			*Cil 3* *(Limitazione giri oltre 6800 per 10s)*	
			B27			*Cil 4*	
						**Sensore temperatura motore**	
	Moto	B5	B29			**Tensione alimentazione** *(spina scollegata)*	**4,5 ÷ 5 Volt**
	Moto	B5	B29			**Segnale** di riferimento *(5 V in diminuzione con l'aumento della temperatura)*	

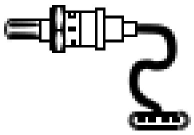
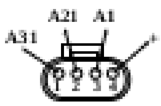
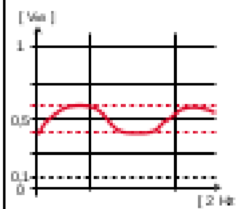
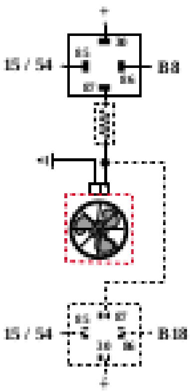
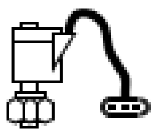
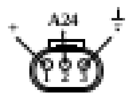
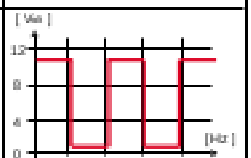
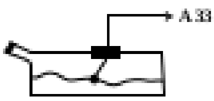
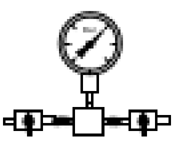
MISURA	CHIAVE	N° CONNETT. CENTRALINA		OPERAZIONI DI CONTROLLO (su spina scollegata)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
SPINA LATO MOTORE B (nero)					
	Stop	*Per le 3 prove successive, collegare il pin 6 della spina A a massa* *(o in maniera descritta su spina A)*			
Volt	Mar	⏚	38	*Cil 1 - 4* **Controllo** continuità primario bobine	**10 ÷ 15 Volt**
			10	*Cil 2 - 3*	
	Mar		28	*Cil 1* **Controllo** comando elettroiniettori *(collegare i pin indicati ad intervalli a massa)* *(scollegare elettropompa)*	***(prova uditiva)***
			36	*Cil 2*	
			37	*Cil 3*	
			27	*Cil 4*	
	Mar		26 ad ⏚	**Controllo** elettrovalvola vapori benzina *(collegare pin 26 ad intervalli a massa)*	***(prova uditiva)***
Ohm	Stop	+ 25	- 35	**Resistenza** sensore di giri / P.M.S.	**1100 ÷ 1400 Ω**
Ohm	Stop	+ 6	- 15	**Resistenza** sensore di battito	**530 ÷ 580 Ω**
Ohm	Stop	+ 32	- 20	**Resistenza** potenziometro acceleratore *(term a - b)*	**1200 ÷ 1250 Ω**
		s 3	- 20	**Variazione** pista potenziometro *(term a - c)*	**0 — 1200 Ω**
Ohm	Stop	18	17	*(tra i term A - D)* **Attuatore del minimo**	**50 ÷ 60 Ω**
		9	19	*(tra i term B - C)*	
Ohm	Stop	+ 5	- 29	*(motore)* **Sensori temperatura** *0 ° C* *10 ° C* *20 ° C*	**9.5 KΩ** **3.8 KΩ** **2.5 KΩ**
		+ 14	- 29	*(aria) (nel sensore pressione assoluta)* *60 ° C* *80 ° C* *90 ° C*	**500 Ω** **300 Ω** **200 Ω**

CENTRALINA	CHIAVE	TERM. CONNETT. CENTRALINA		OPERAZIONI DI CONTROLLO	VALORI e/o OSCILLOGRAMMA DA RILEVARE
(N.B. CHIAVE DISINSERITA RICOLLEGARE CENTRALINA)					
	Stop	⏚		*(tra gruppo centralina e motore)* **Controllo circuito masse** *(tra gruppo centralina e carrozzeria)*	**Max 1 Ω**
	Mar	⏚	A4	*permanente*	**10 ÷ 15 Volt**
			A 17	**Tensione** alimentazione: *a chiave inserita*	

COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA	TERM. CONNETT. COMPONENTI		OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
	**Relè principale** *(portarelè e relè rosso)*					
	Stop			⏚	30	**Tensione** permanente	**10 ÷ 15 Volt**
	Mar			⏚	85	**Tensione** a chiave inserita	**10 ÷ 15 Volt**
				86	85	**Comando** relè *(collegato)*	*(per 5 sec)* **10 ÷ 15 Volt**
				⏚	87	**Per chiusura** relè *(collegato)*	*(per 5 sec)* **10 ÷ 15 Volt**
	**Potenziometro acceleratore**					
	Mar	- B 20	+ B 32	- a	+ b	**Alimentazione**	**4,8 ÷ 5 Volt**
	Moto	- B 20	s B 3	- a	s c	**Segnale** d'uscita *(a riposo)*	**0,8 Volt**
						(a fondo corsa)	**4,8 Volt**
	**Sensore pressione assoluta / temperatura aria**					
	Mar	- B 29	+ B 22	- a	+ b	**Alimentazione**	**4,8 ÷ 5 Volt**
	Moto	- B 29	s B 13	- a	s c	**Uscita** segnale sensore pressione assoluta *Chiave inserita*	**4,2 ÷ 4,5 Volt**
						al minimo	**1,2 ÷ 1,5 Volt**
						Pieno carico	**4,2 ÷ 4,5 Volt**
			B 14	- a	°c	**Segnale** sensore temperatura aria *(in diminuzione con l'aumento della temperatura)*	

	**Sensore di battito**					
	Moto	- B 15	+ B 6	1	2	**Segnale** comando *(Per riduzione anticipo)*	

COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA		TERM. CONNETT. COMPONEN.		OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
Bobina A.T.							
	Moto	⏚	B 38 B 10	⏚	1	*Cil 1 - 4* **Segnale** di comando *Cil 2 - 3*	
Attuatore del minimo							
	Moto	⏚	B 17 B 18	⏚	1 4	**Segnale** comando *(In base variazione carico motore Es. fari,ventole,etc etc)*	
Elettrovalvola vapori benzina *(canister)*							
	Mar			⏚	1	**Alimentazione**	**10 ÷ 15 Volt**
	Moto	⏚	B 26	1	2	**Segnale** comando *(Motore in temperatura giri motore 2000 - 2500)*	
Sonda LAmbda *(a monte)*							
	Mar			+ 4	- 3	**Consenso** alimentazione riscaldamento	*(tensione pulsante)* **10 ÷ 15 Volt** *(10 ÷ 13 Hz)*
	Moto	A 22	A 32	+ 1	- 2	**Segnale** *(motore in temperatura)*	
						Oscillazione — *Miscela ricca*	**0,7 ÷ 0,9 Volt**
						Normale	**0,4 ÷ 0,7 Volt**
						Miscela povera	**0,1 ÷ 0,4 Volt**
						Variazione del tempo di iniezione in relazione al segnale sonda lambda — *0,7 ÷ 0,9 V*	**Diminuzione**
						0,4 ÷ 0,7 V	**Ottimale**
						0,1 ÷ 0,4 V	**Aumento**

COMPONENTI e pin centralina	CHIAVE	TERM. CONNETT. CENTRALINA		TERM. CONNETT. COMPONEN.		OPERAZIONI DI CONTROLLO (le spine sono viste lato collegamento attuatori)	VALORI e/o OSCILLOGRAMMA DA RILEVARE
	Sonda LAmbda *(a valle)*						
	Mar			- 3	+ 4	**Consenso** alimentazione riscaldamento *(subito a freddo ed in determinate condizioni)*	*(tensione pulsante)* **10 ÷ 15 Volt** *(10 ÷ 13 Hz)*
	Moto	A 21	A 31	+ 1	- 2	**Oscillazioni** *(se il segnale oscilla come quello della sonda Lambda a monte, il catalizzatore non assolve alla sua funzione)*	*(quasi stabile 450 ÷ 500 mV)* 
	**Relè elettroventilatore raffreddamento motore**						
	Mar	B4	B8	85	86	**Segnale** comando relè *(1' velocità)* *Superiore a 97 C'*	**10 ÷ 15 Volt**
						Inferiore a 94 C' (stacco)	**0 Volt**
			B 18	85	86	**Segnale** comando relè *(2' velocità)* *(se presente)* *Superiore a 102 C'*	**10 ÷ 15 Volt**
						Inferiore a 94 C' (stacco)	**0 Volt**
	**Sensore velocità**						
	Movimento			1	2	**Alimentazione**	**10 ÷ 15 Volt**
		A 24	⏚	3	2	**Segnale** *(Con vettura in movimento)* *(Lancia Y segnale da quadro strumenti)*	 *(16 impulsi per giro)*
	**Riserva carburante**						
	Stop	A33	⏚			**Valore** *(segnale)*	**10 ÷ 15 Volt**
						(circa 5 litri)	**0 Ω**
	**Pressione carburante**						
	Moto					*(Regolatore pressione carburante interno gruppo elettropompa)*	**3 ÷ 3,5 Bar**

MISURA	CHIAVE	DATI TECNICI	VALORI DA RILEVARE
		Misure di resistenza su Attuatori	
Ohm	Stop	**Singolo elettroiniettore**	**14 ÷ 16 Ω**
Ohm	Stop	**Sensore di giri / P.M.S.** *(term 1 - 2)*	**1100 ÷ 1400 Ω**
Ohm	Stop	**Riscaldamento sonda Lambda** *(term 3 - 4)*	**3 Ω**
Ohm	Stop	**Elettrovalvola vapori benzina**	**35 ÷ 58 Ω**
Ohm	Stop	**Sensore di battito**	**530 ÷ 580 Ω**
Ohm	Stop	**Attuatore del minimo** *(term A - D)* *(term B - C)*	**50 ÷ 60 Ω**
Ohm	Stop	**Potenziometro acceleratore** *(term a - b)*	**1200 ÷ 1250 Ω**
		(term a - c)	**0 → 1200 Ω**
Ohm	Stop	**Sensori temperatura** *(motore)* *(aria) (nel sensore pressione assoluta)* *0 °C*	**9.5 KΩ**
		10 °C	**3.8 KΩ**
		20° C	**2.5 KΩ**
		60° C	**500 Ω**
		80° C	**300 Ω**
		90° C	**200 Ω**
Ohm	Stop	**Bobina A.T.** *(primario)*	**0,5 ÷ 0,65 Ω**
		(secondario)	**6850 ÷ 7850 Ω**

N.B.

Le misure di resistenza sono misurate a circa 20° C direttamente sugli attuatori.

(collegamenti scollegati)

Comando spia temperatura acqua

La centralina elettronica utilizzando il segnale del sensore temperatura acqua, invia un segnale negativo attraverso il pin 3 al raggiungimento di 120 °C con l'accensione della relativa spia.

Procedura di attivazione corretto funzionamento sonde Lambda a monte e a valle

Nel caso:

- sostituzione di una o di entrambe le sonde lambda,

con motore termicamente regimato al minimo e controllo lambda operativo, deve essere effettuata, tramite strumento di diagnosi, una procedura automatica di verifica del corretto funzionamento delle sonde lambda pre e post-catalizzatore.

Se ciò non avvenisse si potrebbe accendere, entro pochi km, la lampada Mil *(problemi di emissioni)* con registrazione in memoria di un codice di errore collegato alla sonda lambda a monte

Procedura apprendimento irregolarità ruota fonica

Nel caso:

- in cui venga sostituito la ruota fonica
- in cui venga sostituito il sensore di giri / P.M.S.
- dopo azzeramento dei parametri autoadattativi
- interventi di riparazione a carico del motore o del cambio,

con motore termicamente regimato, deve essere effettuata una procedura di apprendimento delle irregolarità della ruota fonica ai fini del corretto funzionamento della diagnosi misfire *(l'apprendimento delle irregolarità sui denti della ruota fonica è una condizione indispensabile per poter effettuare la diagnosi "misfire" della mancata combustione)*

Se ciò non avvenisse, si potrebbe accendere la spia Mil in modo lampeggiante con registrazione in memoria permanete di un codice di errore.

Per eseguire l'apprendimento devono essere eseguite le seguenti operazioni:

a) Commutare il contatto chiave sulla posizione ON, avviare il motore; se la spia Mil presente sul quadro di bordo lampeggia, significa che bisogna ancora effettuare l'apprendimento della ruota fonica.

b) Avviare e attendere la regimazione termica del motore

c) Con cambio marcia in posizione folle, eseguire almeno 3 accelerate ad un regime consigliato di 6000 giri / min *(l'apprendimento è possibile a partire da una soglia intorno a 5000 giri / min ma si consiglia di effettuare il rilascio del pedale acceleratore ad un regime motore maggiore alla soglia minima)*

d) Se al termine dell'operazione la spia Mil continua a lampeggiare significa che l'apprendimento non è completato; continuare con le accelerate secondo le modalità citate nel punto precedente fino allo spegnimento della spia.

e) Commutare il contatto chiave sulla posizione OFF e attendere almeno un minuto per la registrazione del dato in memoria permanente dell'informazione.