**TECHNICAL UNIVERSITY OF LODZ**
International Faculty of Engineering

Department of Semiconductor and Optoelectronics Devices, K-27
[***WWW.DSOD.PL***](http://www.dsod.pl)

# *SENSORS and ACTUATORS*

# *Exp 6*

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| ***EXPERIMENT NO:*** | **6** |
| ***EXPERIMENT TITLE:*** | **Sensors and actuators used Ignition Internal Combustion Engine system** |

| ***LABORATORY GROUP*** | | | ***Program/Term*** | |
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| ***Lecturer:*** | |
| ***Data date of experiment:*** | |
| ***Data of submitted report :*** | |
| ***Mark:*** | |
| ***Comments*** | |

**Goal:**

**The main goal of the experiment is to familiarize students with application of sensors and actuators in control system used to control a spark ignition internal combustion engine.**

**SPECIFICATION:**

The following instruments and software are used:

**Instruments**

1. Model of the control system of Internal Combustion Engine with spark ignition.
2. RIGOL DM3056 multimeter
3. 4 channel oscilloscope RIGOL
4. APPA Multimetr

**Software:**

1. LabView a software platform for Integration of hardware and software for measuring and control purposes.
2. Excel packed

THEORY

**INTRODUCTION**

One of the example of a digital control system with a numerous of sensors and actuators is a Bosch MOTRONIC (an abridgement of ″motor electronics‟) a system which controls spark-ignition combustion engines introduced in 1979. Its version ML 4.1 combines air-fuel mixture preparation and ignition systems in a single embedded control module. A set of sensors and actuators are connected physically to ML 4.1. The task of ML 4.1 is to control SI ICE (Spark Ignition Internal Combustion Engine).

**Please visit:**

**http://www.mbcscap.com/presentations/AE/engines/fourcycle%20big.html**

## 1. Theoretical basis ML4.1 engine management overview

The key functions of the Bosch ML4.1 engine management system are:

- To control the amount of fuel supplied to each cylinder
- To calculate and control the exact point of fuel injection
- To calculate and control the exact point of ignition on each cylinder
- To optimize adjustment of the injection and ignition timings to deliver the maximum engine performance throughout all engine speed and load conditions
- To calculate and maintain the desired air/fuel ratio, to ensure the 3 way catalysts operate at their maximum efficiency
- To maintain full idle speed control of the engine
- To ensure the vehicle adheres to the emission standards
- To ensure the vehicle meets with the fault handling requirements, as detailed in the 'On-board diagnostic II' (OBDII – On Board Diagnostic ) legislation
- To provide an interface with other electrical systems on the vehicle

To deliver these key functions, the engine management system operate upon based on several inputs and delivering signal controls at the outputs. As with all electronic control units, the ECM needs information regarding the current operating conditions of the engine and other related systems before it can make calculations , which determine the appropriate outputs.

The Motronic Bosch system optimizes engine performance by interpreting signals from numerous vehicle sensors and other inputs. Some of these signals are produced by the actions of the driver, some are supplied by sensors located on and around the engine and some are supplied by other vehicle systems.

The inputs are as follows:

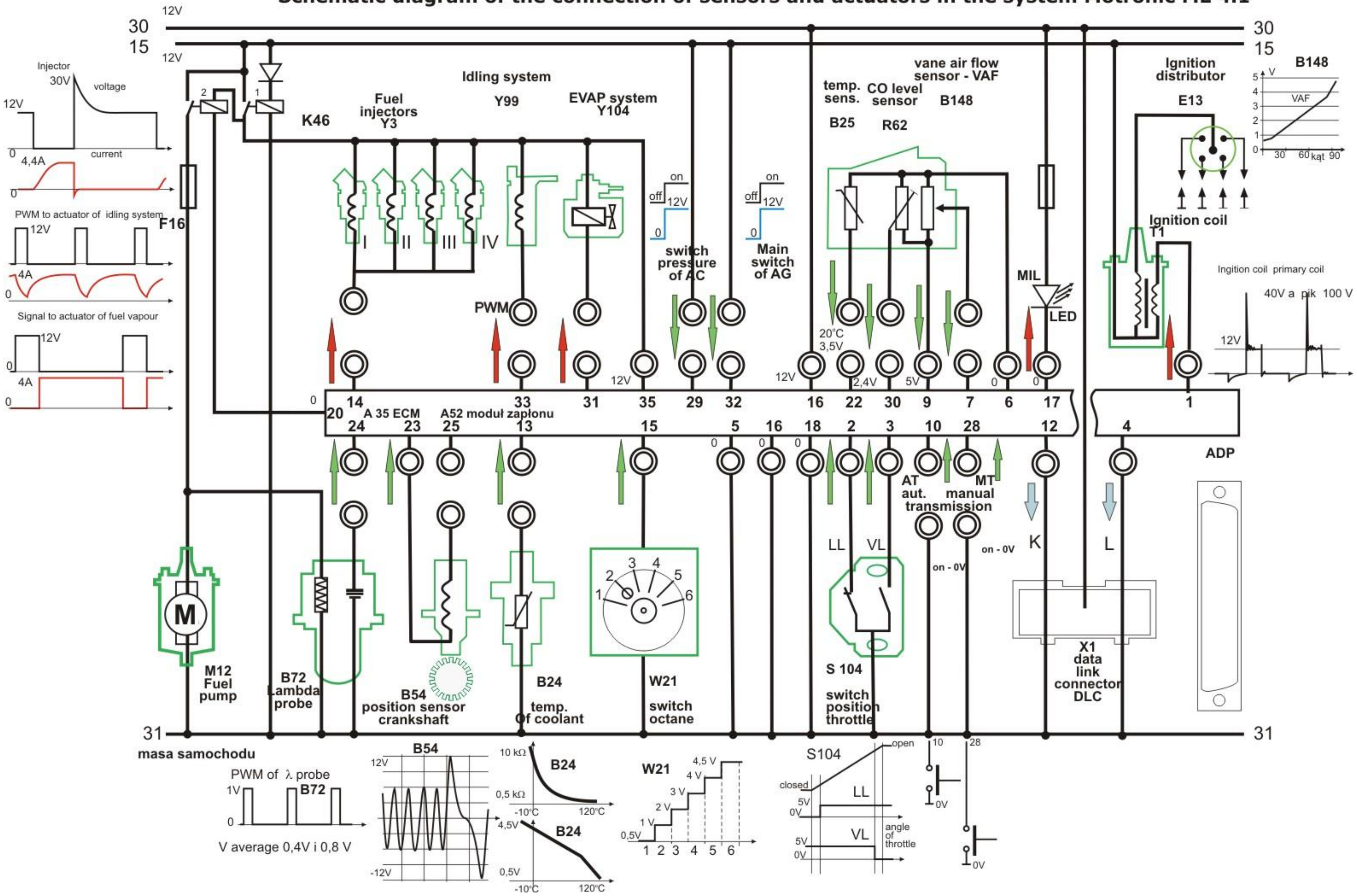
- Engine coolant temperature sensor (ECT)
- Air mass flow and temperature sensor (MAF): (a)vane air flow sensor – VAF; (b) CO level sensor; (c) temperature sensor
- Throttle position sensor (TPS)  - switch position throttle
- Crankshaft position sensor (CKP) and Camshaft position sensor (CMP)
- Oxygen sensors (HO2) Lambda sensor
- Fuel octane signal (resistance sensor)
- Automatic or manual gearbox information signal
- Main switch of AG signal
- Switch pressure of AC signal

3. Actuators

- Fuel injector
- Ignition system
- Idling
- EVAP
- MIL

The ECM is programmed during manufacture by writing the program and the engine 'tune' into the Flash EPROM (erasable programmable read only memory)

## Schematic diagram of the connection of sensors and actuators in the system Motronic ML 4.1



Signal processing

Basic ignitron timing is stored In a two dimensional map and the engine load and speed signals determines the ignition timing.
The main engine load sensor is the AFS and engine speed is determined from the CAS signal.
Correction factors are then applied for starting, idle, deceleration and part and full-load operation.
The main correction factor is engine temperature (CTS).
Minor correction to timing and AFR are made with reference to the ATS and TS signals.
The basic AFR is also stored in a two dimensional map and the engine load and speed signals determines the basic injection pulse value.
Motronic calculates the AFR from the AFS signal and the speed of the engine (CAS)
.
The AFR and the pulse duration are then corrected on reference to ATS, CTS, battery Voltage and position of the TS.
Other controlling factors are determined by operating conditions such as cold start and warm-up, idle condition, acceleration and deceleration.
Motronic accesses a different map for idle running conditions and this map is implemented whenever the engine speed is at idle.
Idle speed during all warm-up and normal hot running conditions are maintained by the ISCV. However, Motronic makes small adjustments to the idle speed by advancing or retarding  the timing, and this results in an ignition timing that is forever changing during engine idle

The Motronic 4.1 system was used on Opel / Vauxhall eight-valve engines from 1987–1990,[7] and some PSA Peugeot Citroën XU9J-series engines.[4]
Fuel enrichment during cold-start is achieved by altering the timing of the main injectors based on engine temperature, no "cold start" injector is required. The idle speed is also fully controlled by the Motronic unit, including fast-idle during warm-up (therefore no thermo-time switch is required).
The 4.1 system did not include provision for a knock sensor for timing adjustment. The ignition timing and fuel map could be altered to take account of fuels with different octane ratings by connecting a calibrated resistor (taking the form of an "octane coding plug" in the vehicle's wiring loom) to one of the ECU pins, the resistance depending on the octane adjustment required.[7] With no resistor attached the system would default to 98 octane.

There is has a single output for the injectors, resulting in all injectors firing simultaneously. The injectors are opened once for every revolution of the engine, injecting half the required fuel each time.[7]

## DESCRIPTION OF SELECTED SENSORS:

- **Engine Coolant temperature sensor (B24)** – is absed on NTC sensor. Termistor NTC (ang. - Negative Temperature Coefficient ) is a semiconductor whose resistance decreases with increasing temperature. In practice, the greater use of NTC thermistors were due to the more linear course of the relationship between resistance and temperature.
- **Inlet Aire temperature sensor (B25)** - NTC type

Relation for NTC sensor:

$$\boxed{R_T = R_{T_{ref}} e^{B\left(\frac{1}{T}-\frac{1}{T_{ref}}\right)}}$$

T- temperature in K

B= 4500 +/- 5% (material constant)

$RT_{ref}$ =2500 +/-10 % (reference value at t=25°C)

$T_{ref}$= 25 + 273 = 298K

Resistance measurement - direct measurement method: No current through circuitry: ohmmometer connect to terminals: "13" and "5"

Note: The measurement of the indirect method only control measurements. Indirect method: calculation of reissuance based on Voltage and current

Measurements:

| temp t | temp T= 273+t | Direct measurement method | Indirect measurement method | | | Approximation Lest square method for direct measurement method |
|---|---|---|---|---|---|---|
| | | | Voltage: VRT | Current IRT | Resistance RRT=VRT/IRT | |
| oC | K | Ω | V | mA | Ω | Ω |
| -13 | 260 | 9318 | 4,55 | 0,481 | 9459 | 7881 |
| -10 | 263 | 8164 | 4,49 | 0,546 | 8223 | 7140 |
| -5 | 268 | 6898 | 4,39 | 0,642 | 6838 | 6087 |
| 0 | 273 | 5443 | 4,24 | 0,775 | 5471 | 5219 |
| 5 | 278 | 4266 | 4,10 | 0,948 | 4325 | 4500 |
| 25 | 298 | 2665 | 3,70 | 1,307 | 2831 | 2614 |
| 40 | 313 | 1617 | 3,39 | 1,866 | 1817 | 1820 |
| 90 | 363 | 977 | 2,37 | 2,560 | 926 | 676 |
| 120 | 393 | 500 | 0,53 | 1,000 | 530 | 421 |

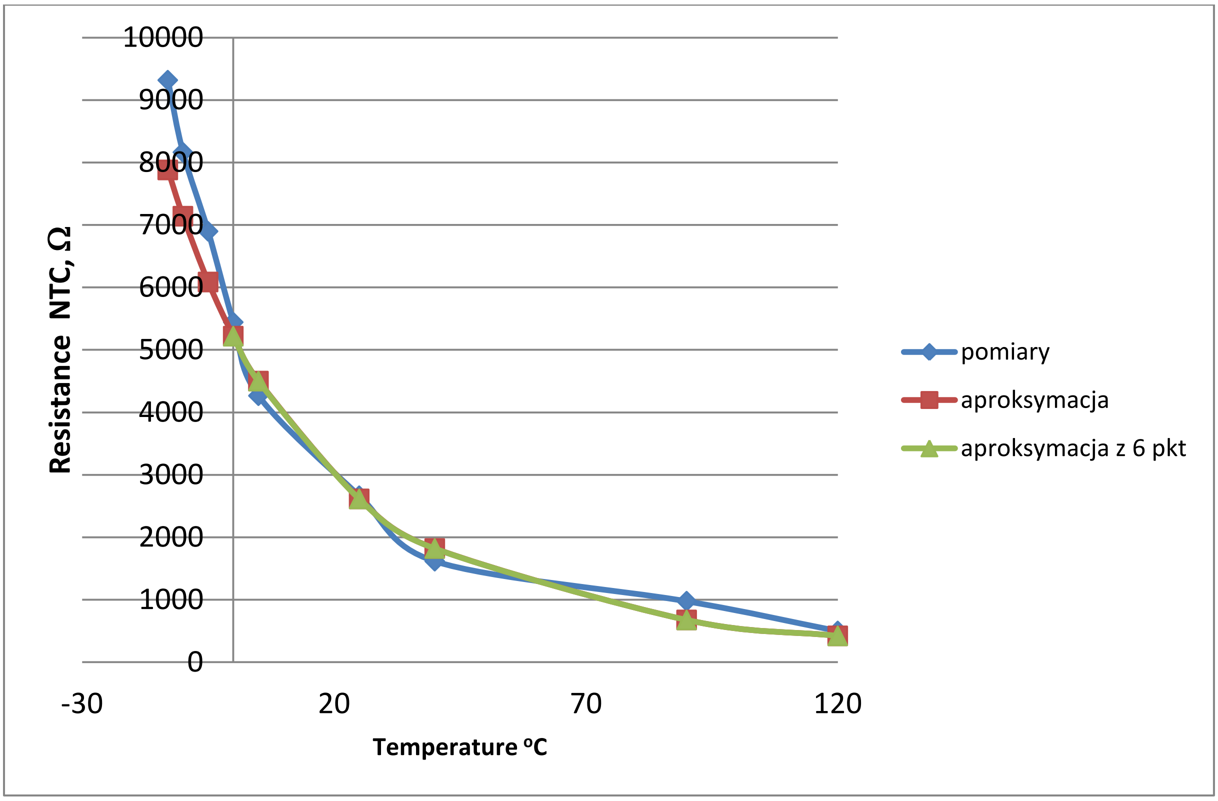



Fig 1. Experimentally determined characteristics of the temperature sensor OPEL and its approximation of all points and 6 Measurement points are considered the most reliable (note the other outside 6 assigned "weight" to zero.

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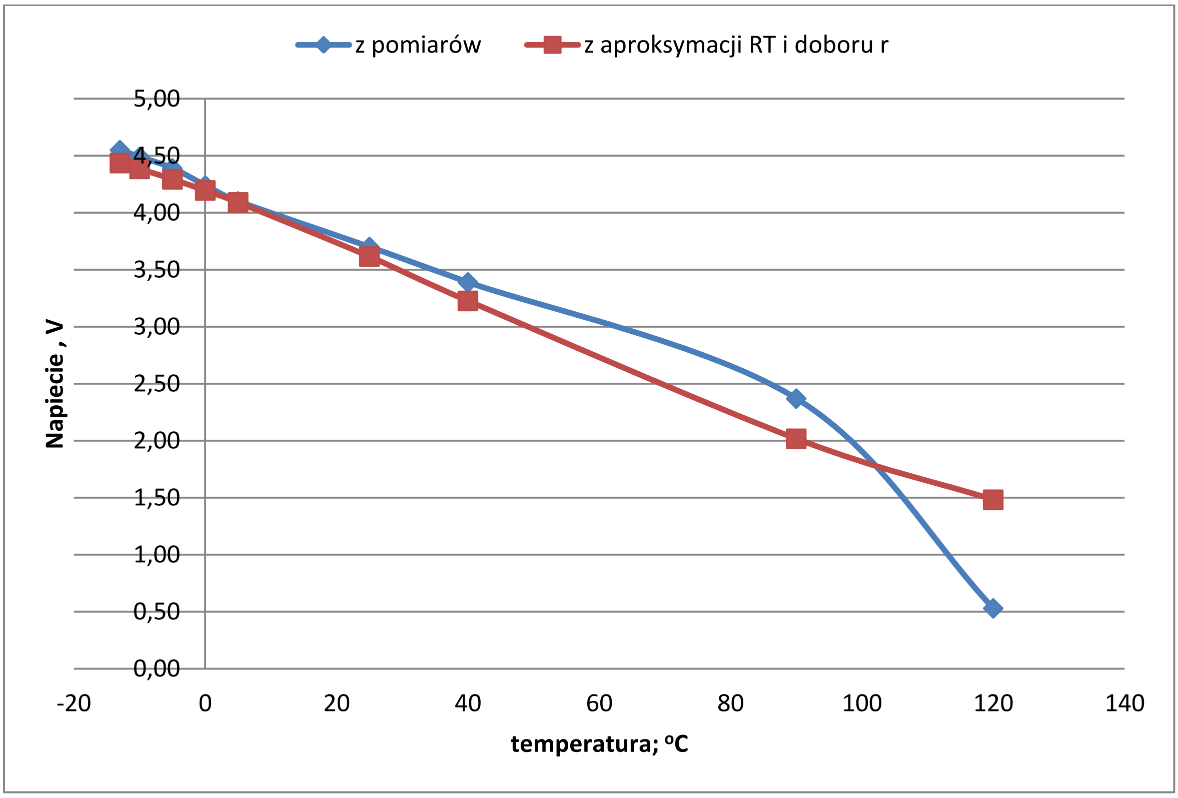



Figure 2 voltages on the output of the sensor (input to ML4.1) tightens "13" resistor r is the voltage output liberalizing

The intermediate results of the linearization method of least squares below

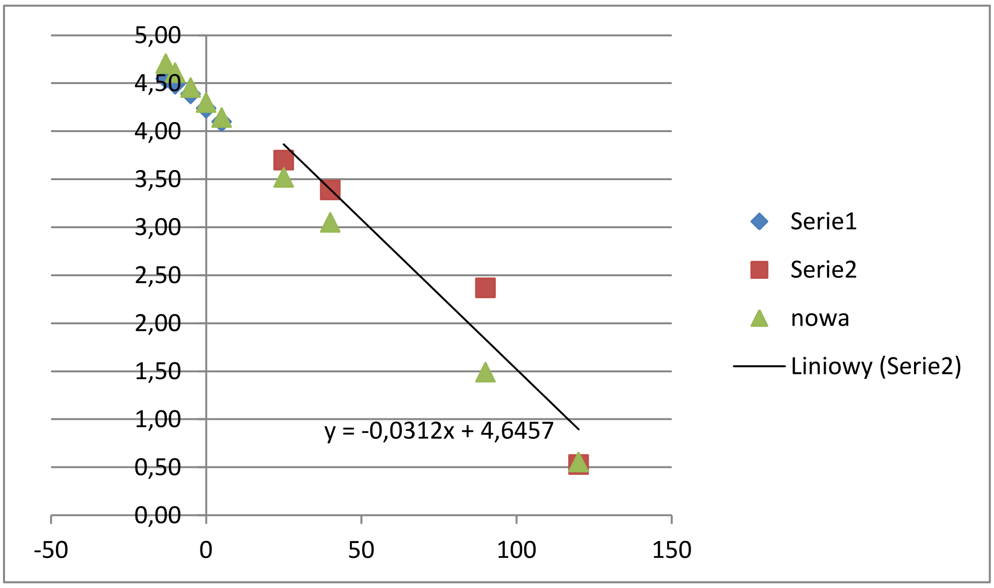



Fig 3. Voltage vs. Temperature with its linwarisation

For Voltage calculation apply: Resistance of 10 KΩ, supply voltage 5 V

**Vane Air Flow VAF (B148)** - It measures the volume of air flowing through it. Air flow causes a shift in the mobile flap combined with moving the arm resistive path. This changes the resistance of the sensor and a varying output voltage proportional to the volumetric flow rate of air flow. In addition, the meter has a temperature compensation sensor.

Voltage at the terminal „7” and GND

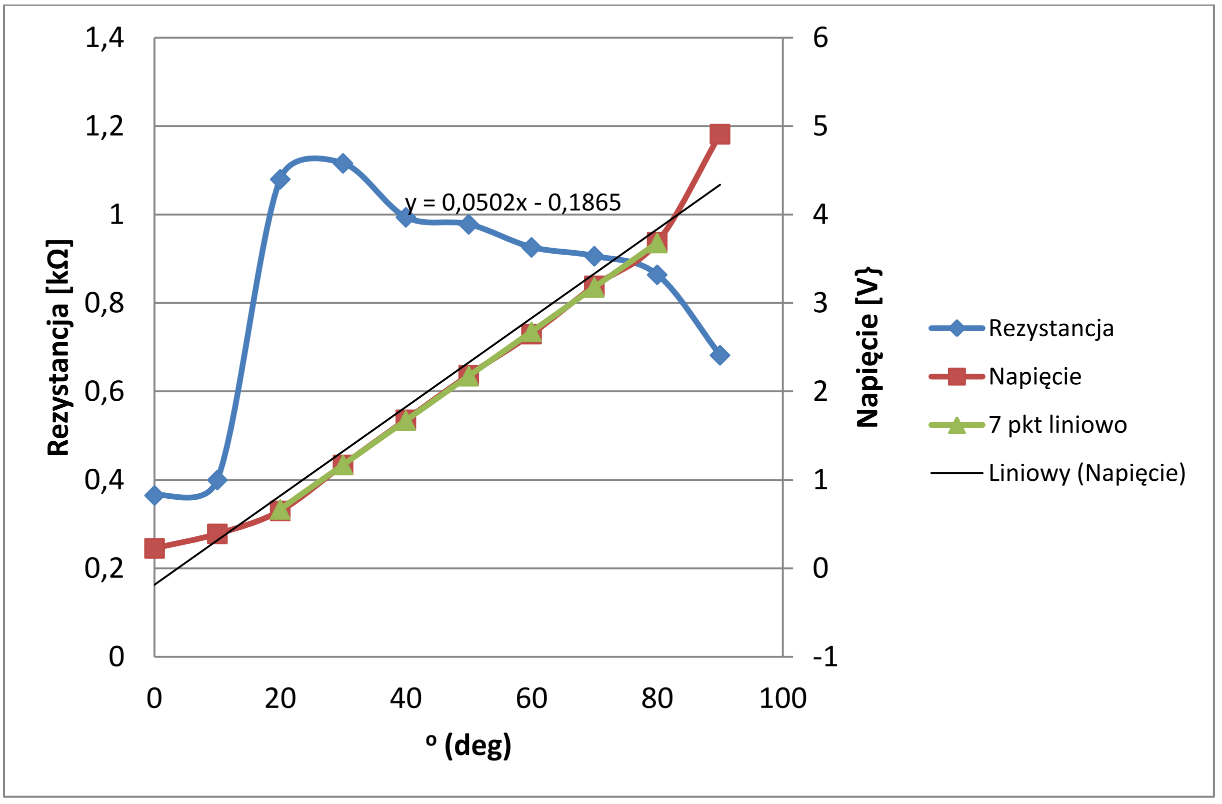



Fig. 4. Vane Air Flow VAF Resistance vs. Angle of vane (corresponds to angle of accelerometer.

The crankshaft position sensor / speed sensor (B54) - in order to measure the crankshaft position sensor works with a shield in the form of measuring gear (in our case, there are other types). In the case of magneto-inductive sensor amplitude depends on the peripheral speed of the wheel, the gap between the teeth and the sensor, the shape of the teeth, the characteristics of the magnetic sensor and how to fix. Alternatively, the magneto-inductive sensors is also used Hall Effect sensors. is one of the most important elements of the vehicle. The output signal from the sensor signal is called the angular position of the crankshaft. On the basis of these signals can be calculated engine speed signal. In many electronic control systems, internal combustion engine speed information and the instantaneous position of the crankshaft is obtained on the basis of a signal from one and the same sensor.

The crankshaft position sensor has three terminals:

- The mass
- Contact the signal
- screen

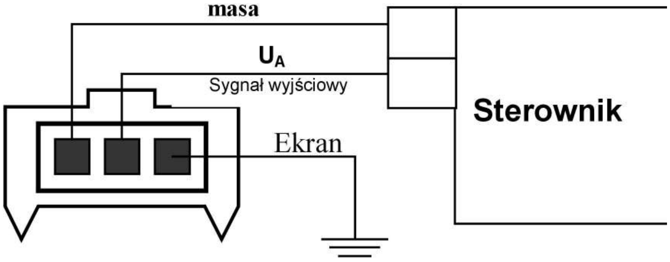



Figure 1 - Connecting the crankshaft sensor**.**

Operation of the inductive sensor uses the magnetic field change. It is called the change width of the air gap between the sensor, which is fixed in one place, and ferromagnetic elements of the rotating disk, which in our case the gear. Every time one of the gear teeth is close to the sensor, where the coil windings are wound, there is an electrical impulse. Variable intensity of current flow induces an alternating voltage in the coil windings sensor. On the basis of the voltage amplitude and the pulse rate is calculated rotational speed of the crankshaft. It is also worth noting that the crown gear has a wider gap corresponding to two, TDC (top dead center) of the piston.

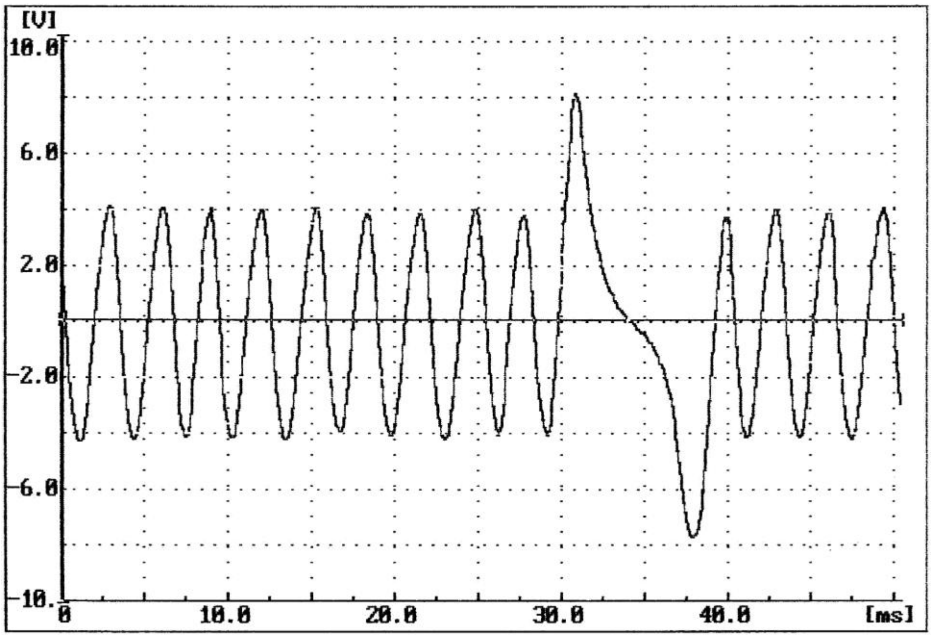
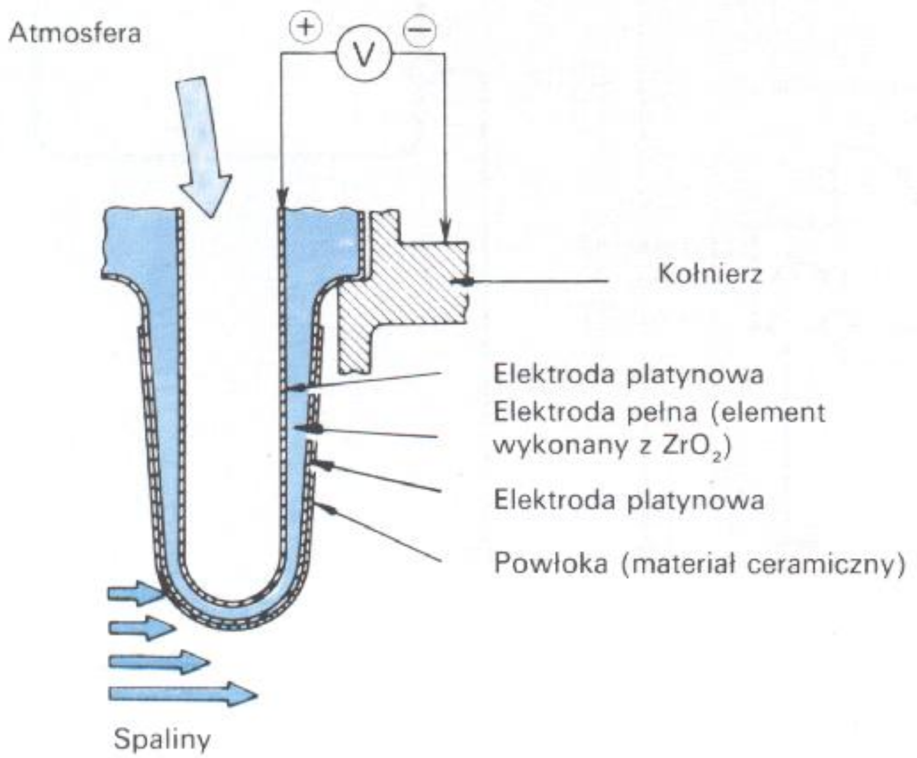


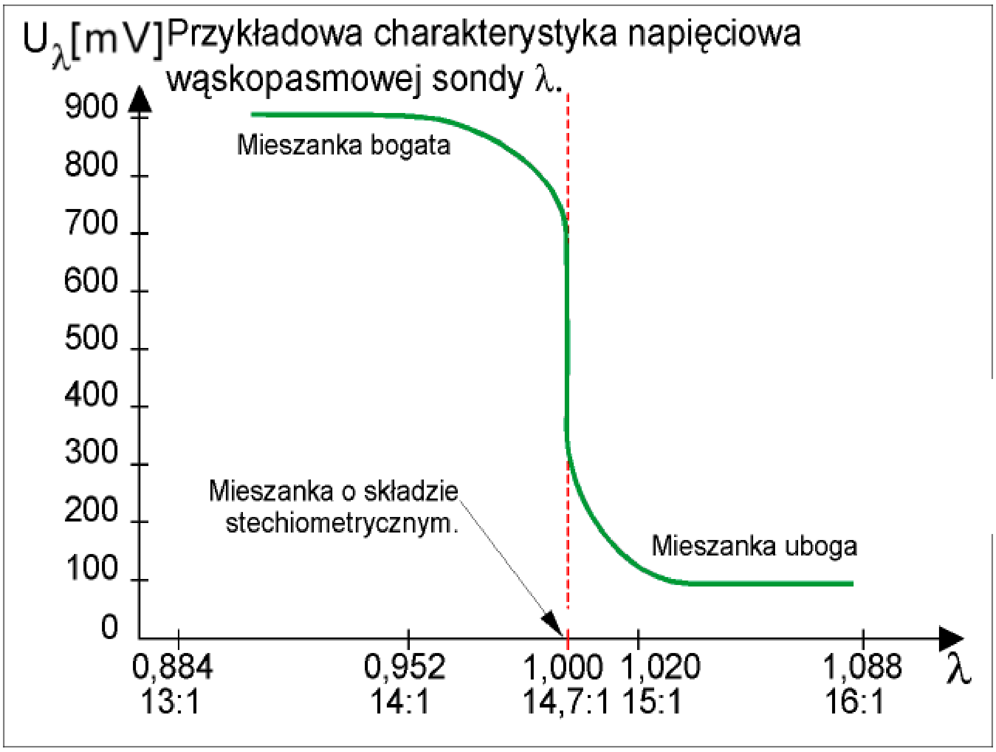

Figure 2 - The amplitude of the voltage signal of the inductive sensor

The oscillogram see waveform of an inductive sensor. Rim wheels on each half has 58 teeth + 2 blank spaces = 60 teeth.
Each tooth maps the amplitude is one of 58, two hollow protrusions maps the signal of greater width.

**Lambda (B72)** - is a sensor for measuring the oxygen content in the exhaust gas, which reflects the efficiency of the combustion of the fuel mixture. It is mounted in the exhaust petrol engine. Its application allows for precise dosing of the composition of the fuel-air mixture. For our array emulated by changing the duty cycle and pulse frequency.




Exhaust flow around part of the measuring probe which is screwed directly into the exhaust (tailpipe col) just behind the exhaust manifold and before the catalytic converter. Note that the temperature probe is about 300 ° C. The probe voltage obtained depends on the composition of the mixture.



Uλ[mV]
Przykładowa charakterystyka napięciowa wąskopasmowej sondy λ.
900
800
700
600
500
400
300
200
100
0
Mieszanka bogata
Mieszanka o składzie stechiometrycznym.
Mieszanka uboga
0,884
13:1
0,952
14:1
1,000
14,7:1
1,020
15:1
1,088
16:1
λ

**EXPERIMENT:**

**TASK 1:**

Identification of the sensor and determine the scope of their work in a position with the ignition off and the ignition key attached.

With the meter range sensors take measurements and compare them to the table:

| Circuitry/sensor | range | measurements | | renarks |
|---|---|---|---|---|
| | | MIN | MAX | |
| Circuit ground controller * | (0,00 ÷ 0,10) V | | | SI off |
| Sensor ground circuit of the intake air | (0,00 ÷ 1,00) V | | | |
| Ground circuitry speed sensor | (0,00 ÷ 1,00) V | | | |
| Voltage of controller power supply | (10,00 ÷ 14,00) V | | | |
| Ground voltage of the main relay coil | (0,00 ÷ 2,00) V | | | |
| Ground terminal of the fuel pump relay coil | (0,00 ÷ 2,00) V | | | |

| Circuitry/sensor | range | Pomiary | | Uwagi |
|---|---|---|---|---|
| | | MIN | MAX | |
| main relay coil | (10,00 ÷ 14,00) V | | | SI on |
| the fuel pump relay coil | (10,00 ÷ 14,00) V | | | |
| Coolant tem. sensor | (0,10 ÷ 4,20) V | | | |
| Tem. Of air intake | (0,10 ÷ 4,20) V | | | |
| Injectors | (10,00 ÷ 14,00) V | | | |
| Idling valve | (80 ÷ 15000) Hz | | | |
| Valve of the filter with active coal | (10,00 ÷ 14,00) V | | | |
| DC of VAF supply | (4,00 ÷ 6,00) V | | | |
| VAF sensor | (0,10 ÷ 1,00) V | | | |
| Ignition coil | (10,00 ÷ 14,00) V | | | |
| Octane corrector | (0,50 ÷ 5,50) V | | | |
| CO potenciometer | (2,20 ÷ 2,80) V | | | |
| Switch full throttle (full load) | (0,00 ÷ 2,00) V | | | |
| Idle switch (throttle closed) | (4,00 ÷ 6,00) V | | | |

*measurements taken at pins located in the model

## TASK 2

**Coolant NTC sensor**

| temp | temp | Direct measurement |
|---|---|---|
| [°C] | [K] | [Ω] |
| -13 | | |
| -10 | | |
| -5 | | |
| 0 | | |
| 5 | | |
| 25 | | |
| 40 | | |
| 90 | | |
| 120 | | |

| Voltage V | |
|---|---|
| [V] | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

2.a Present a graph: *R=f(T) and V=f(T)*

2.b approximate *R=f(T)* and *V=f(T) using solver facilities of EXCEL*

## TASK 3

VAF measurements

| The percentage of throttle opening | Voltage | resistance |
|---|---|---|
| [%] | [V] | [Ω] |
| 0 | | |
| 20 | | |
| 40 | | |
| 60 | | |
| 80 | | |
| 100 | | |

3.a Present a graph: *R=f(T) and V=f(T)*

3.b approximate *R=f(T)* and *V=f(T) using solver facilities of EXCEL*

## TASK 4

**RPM sensor**

Present on oscilloscope the three waveforms for speeds (800, 1600, 2400 by speed meter indications mounted on the bench). Determine the pulse period, the number of teeth, the rotational speed of the crankshaft, and the rotational speed of the distributor.

## TASK 5

Investigation of Lambda sensor

Frequency and complete set with the knobs on the board. For positions shown in the table using the amplitude of the oscilloscope, pulse duration, the duration of the positive portion and then calculate the fill factor.

| the position of the knob of the frequency adjustment | the position of the knob of the duty factor adjustment | Positive part of pulse train $t_p$ | Duty factor $D=t_p/T$ | Amplitude | Average voltage: $V_{avg}=A*D$ |
|---|---|---|---|---|---|
| T[s]; f[Hz] | - | ms | % | V | V |
| leftmost<br>T=…..<br>f=….. | leftmost | | | | |
| | central | | | | |
| | rightmost | | | | |
| central<br>T=…..<br>f=….. | leftmost | | | | |
| | central | | | | |
| | rightmost | | | | |
| rightmost<br>T=…..<br>f=….. | leftmost | | | | |
| | central | | | | |
| | rightmost | | | | |

f – frequency, T – period (readings from oscilloscope)

## Literature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2. *Bosch : Czujniki w pojazdach samochodowych, WKiŁ, Warszawa, 2002.*
3. *Herner A., Riehl H.J.: Elektrotechnika i elektronika w pojazdach samochodowych, WKiŁ , Warszawa, wyd. 2, 2004.*
4. *Ocioszyński J.: Zespoły elektryczne i elektroniczne w samochodach, WNT, W-wa, 1999.*
5. *Instrukcja zintegrowanego systemu MOTRONIC ML 4.1*


Materiały dodatkowe:

1. *Dziubiński M., Walusiak S., Ocioszyński J.: Elektrotechnika i elektronika samochodowa , Wyd. Pol. Lubelskiej, 19993.*
2. *Hebda M.: Podstawy diagnostyki pojazdów, WKiŁ, 1982.*
3. *Koziej E.: Maszyny elektryczne pojazdów samochodowych, WNT, Warszawa,1982*

**Additional information:**

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International Faculty of Engineering

**LABORATORY OF MEASUREMENTS**

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| ***EXPERIMENT NO:*** | **6** |
| ***EXPERIMENT TITLE:*** | **Testing of signals of sensors and actuators in control system for Internal Combustion Engine** |

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| ***Data of submitted report :*** | |
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