Considerations regarding the influence of inappropriate electronic throttle unit operation on pollutant emissions of internal combustion engines

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Abstract. The quality of the fuel mixture in the cylinders of an internal combustion engine is determined by the electronic control unit based on the co-operating information with the electronic throttle unit. For this reason, any malfunction of the components of the electronic throttle unit strongly influences the quality of the fuel mixture and the performance of the internal combustion engines. In this context, in this paper, experimental and theoretical researches were carried out by simulating the failures that can occur at the level of the electronic throttle unit and their influence on the pollutant emissions of the internal combustion engines.

1. Introduction
The quality of the air-fuel mixture strongly influences the performance of internal combustion engines. The correct dosage depends on the quality of the information received by the engine electronic control unit (ECU_engine) and the technical state of the ignition system and fuel supply system execution elements. The technical condition of the sensors and the execution elements also influences the polluting emissions of the internal combustion engines [1]. This paper analyzes the influence of the technical state of the electronic throttle unit on the performances of a spark ignition engine, and then proposes a wider analysis regarding the influence of the technical state of other elements on the performance of the same engine. The electronic throttle unit (or Electronic Throttle Body – ETB) have the following components: (Figure 1):
- the butterfly valve, which controls the mass of air entering the intake manifold;
- the actuator of the butterfly valve, which holds the valve in a specific position according to the operating state of the engine, based on the signal coming from the ECU_engine;
- the Throttle Position Sensor (TPS), which measures in every given moment of time the angular position and sends this value through a signal to the ECU_engine;

The presented design solution allows rigorous control of the throttle position and, furthermore, the determined information can flow through the car's data communication network and can be used by other system’s control units (injection, traction control, etc.).

The information about the airflow allowed in the engine cylinders is processed by the ECU_engine which sets the air-fuel dosage in accordance with the engine operating mode, as follows:
- calculates the rotational speed of the butterfly valve;
- based on angle and rotation speed information, sets the opening time of the injectors;
- adjusts fuel flow, to achieve the air-fuel dosing at optimal values.
Obviously, a correction must be made based on air density by taking into account temperature and pressure variations. This information reaches the ECU\textsubscript{engine} from the temperature and air pressure sensors in the intake manifold.

The TPS sensor (Figure 2) is mounted on the butterfly valve shaft, and it is constructively constituted by a potentiometer whose resistance varies linearly with the opening of the throttle. Because the potentiometer cursor is mounted on the throttle shaft, as it rotates it will generate the potentiometer output voltage change proportional to the angular position of the butterfly valve.

The butterfly valve switch actuator is a stepper motor on which the throttle is mounted. In this constructive version, the speed and rotation angle of the rotor in the stator (fix coil) are controlled very precisely by the ECU\textsubscript{engine}.

2. The typology and effects of ETB failures

A first category of malfunctions [2] that can lead to inappropriate ETB operation include:

- inconsistency between the throttle limit positions (fully closed / fully open) and the corresponding values stored by the ECU\textsubscript{engine} (lack of throttle position adjustment);

- the relative displacements between the butterfly valve shaft and the potentiometer cursor in the TPS sensor assembly;

- solid chemical deposits in the area of the throttle actuation or penetration into the motor gears in the actuator assembly;

Due to these faults, the TPS sensor will selectively transmit (with random sampling steps) to the ECU\textsubscript{engine} the current values of the throttle position. These phenomena will generate an inappropriate response of the ECU\textsubscript{engine} to the actual position of the butterfly valve, generating a correlation with delay and at random intervals between:

- the throttle opening and the air-fuel mixture enrichment trend;

- the throttle closing and the tendency of the air-fuel mixture to leak;

The same phenomena also occur in the case of a malfunction of the TPS sensor potentiometer (decalibration of the sensitive element): runway wear on the travel area of the cursor, corresponding to the most frequent load regimes. In these cases, when rotating the butterfly valve continuously, the variation of the sensor output voltage will show random jumps.

Another type of fault can occur at the ETB connection circuitry as follows:

- open circuit (interrupted) at the level of ETB components connection: actuator solenoid winding, track or sensor cursor;

- open circuit in the connection path between ETB and the ECU\textsubscript{engine};
- imperfect contacts at the ETB or ECU\textsubscript{engine} connector level;
- defects in the wiring between ETB and ECU\textsubscript{engine} (damaged insulating layer, short-circuit between conductors or short-circuit to ground).

These failures cause an interruption in the electronic link either between the ECU\textsubscript{engine} and the throttle actuator (in which case to the actuator will no longer reach the throttle control information) or between the TPS sensor and the ECU\textsubscript{engine} (in which case to the ECU will no longer reach the position of the throttle). In these situations \cite{4}, the ECU\textsubscript{engine} will use a constant value (failure value) of the position of the butterfly valve, regardless of the requirements of the engine operating mode, to determine the amount of fuel injected according to the admissible air flow rate.

In conclusion, the existence of a fault in the ETB operation will cause a lack of correlation between the engine load and the required dosage of the mixture, which at the engine level is manifested by irregular operation, uneven acceleration / deceleration, increase of idling speed or speed limitation and its fluctuations around a level value.

3. Experimental research

The first experimental research \cite{2,3} was carried out by changing the ETB's technical state. To do this, a signal generator (Figure 3) is coupled to the ETB pair connector, which transmits to the ECU a value different from the operating norm. Each type of transmitted signal corresponds to a failure described above.

Experimental tests were performed on a K4M engine with the following features: fuel supply - petrol injection; no. cylinders - 4 in line; Cubic capacity - 1598 cm\textsuperscript{3}; rated power - 82 kW (110 hp) at 6000 rpm; maximum torque - 145 Nm at 4250 rpm.

Five experimental tests P0 ÷ P4 were performed, as follows (Figure 4):

- **P0** test - normal engine operation (without ETB failure).
- **P1** test - short circuit simulation on the wiring path between ETB and ECU\textsubscript{engine}. This malfunction was simulated by making a direct connection between ETB input and output pins.
- **P2** test - circuit interruption simulation on the wiring path between ETB and ECU\textsubscript{engine}. This failure was simulated by disconnecting the ETB connector.
- **P3** test - failure simulation corresponding to a constant output voltage of the TPS or supply of the throttle actuator. The simulation of this failure was accomplished by transmitting a constant voltage of US = 0.75V to the ECU\textsubscript{engine} with the signal generator.
- **P4** test - simulation failure specific to the existence of a rectangular oscillation voltage at the TPS output or the throttle actuator supply. The simulation of this failure was achieved by transmitting to the ECU\textsubscript{engine} via the signal generator a rectangular voltage with the oscillation frequency f = 0.3Hz, the lower variation limit US = 0.65V, the upper variation limit of US =0.93V.

The duration of each experimental test was 10 seconds and consisted in accelerating the engine from idle speed (n0 = 690 rpm) to n = 4000 rpm. During the experimental tests \cite{3,4}, the following parameters characterizing the engine operation were monitored: engine speed, throttle position, potentiometer voltage in the TPS \cite{5}, accelerator pedal position, estimated airflow in the intake manifold, instantaneous fuel consumption and the concentrations of pollutant emissions from the exhaust manifold of the engine (unburned hydrocarbons - HC and carbon monoxide – CO).

Another set of experimental tests \cite{6,7} was carried out on the same engine under the same conditions but with changing the technical state of other elements of the supply and ignition systems as follows:

- **P5** test - Engine running without error codes / no malfunctions;
- **P6** test - The engine having the power supply to the ignition coil of cylinder no. 1 interrupted;
- **P7** test - The engine having the power supply of the air temperature sensor in the intake manifold interrupted;
- **P8** test - The engine having the power supply of both the ignition coil of cylinder no. 1 and the air temperature sensor in the intake manifold interrupted.
Figure 3. Instrumentation of the engine for the experimental research:
1 - ETB connector; 2 - ETB pair connector; 3 – ECU engine pair connector; 4 - signal generator connector; 5 - ETB; 6 – ECU engine; 7 - signal generator

4. Results of the experimental research
When a malfunction appeared in the ETB operation, the ECU engine used for the butterfly valve position, the constant value $\xi = 18.77\%$ (fault value), regardless of the engine operating mode. This phenomenon determined the setting of the idling speed to a value $n_0 = 1520$ rpm, compared to $n_0 = 690$ rpm the value corresponding to the normal operation (Figure 5).

At null load, the value $\xi = 18.77\%$ is superior to the position of the butterfly valve corresponding to the faultless operation of the engine $\xi_0 = 12.90\%$. For this reason the ECU engine will estimate that a larger amount of air will be allowed in the engine cylinders (Figure 6) and will control the increase of the injected fuel flow (Figure 7). In conclusion, under idle, the engine will work with richer blends than normal operating requirements.

Figure 4. Output voltage variation of the TPS ($U_s$) [V] versus time [s]

Figure 5. Engine speed variation ($n$) [rot/min] versus time [s]
At acceleration, as the valve opens, the admitted air flow increases, requiring a corresponding increase in the amount of fuel injected and, implicitly, of the fuel injection time. However, as the fault value of the butterfly valve position remains constant ($\xi = 18.77\%$), the ECU engine will not receive information regarding the need to increase the injected fuel flow. Therefore, the engine will work with increasingly poor mixtures, a phenomenon that caused the engine to run unevenly at constant loads (Figure 5).

The pollutant emissions from the experimental tests are shown in table 1 (the measurements were performed at idle speed and at $n = 2500$ rpm).

During transient processes [8], the inconsistency between the amounts of fuel required to be injected into the engine cylinders and the actual injection time controlled by the ECU engine results in uneven accelerations / decelerations.

Maintaining a constant value for the position of the butterfly flap by the ECU engine causes the engine speed and its oscillations to be limited around a range of approx. $n = 2350$ rot/min.

**Table 1.** Pollutant emissions from the exhaust manifold during the experimental tests

| Operating state | Test P1 | Tests P1÷P4 |
|-----------------|---------|-------------|
| **HC [ppm]**    | Idle speed | 1          | 3          |
|                 | $n = 2500$ rot/min | 1          | 7          |
| **CO [% vol]**  | Idle speed | 0.001      | 0.002      |
|                 | $n = 2500$ rot/min | 0.004      | 0.002      |

All the described phenomena negatively influence the functional and performance engine parameters. Figure 7 highlights the increased fuel consumption. Concerning pollutant emissions, Table 1 shows the measured values of the pollutant (HC and CO) emissions in the exhaust manifold.
determined in the engine operating conditions corresponding to the tests from P0 to P4. There is a significant increase in hydrocarbon and CO emissions. At 2500 rpm the carbon oxide concentration was reduced compared to the normal engine operating mode because the dosage was incorrect. The engine worked irregularly [9] and its performance diminished. P5-P8 tests were not relevant for engine pollutant emissions.

5. Results of the experimental research

As a result of the experiments, it has been found that the electronic throttle unit, by its functional role in the air-fuel mixture process, sensibly influences the evolution of the entire combustion process in the engine cylinders.

Depending on the type of fault that may occur at the ETB level, the impacts on engine performance can be classified into three categories:
- minor, which, although it causes the change of the values of characteristic quantities (increase in fuel consumption, the concentration of pollutant emissions in the exhaust gases), the engine remains functional;
- critical (diminution of functional parameters and engine performance), which appreciably affect the good operation of the engine;
- damage (non-uniform engine operation, speed limitation, increased idling speed, hesitating accelerations / decelerations) that make it impossible to drive safely.

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