PWM CONTROL METHOD IN AUTOMOTIVE MECHATRONICS – TRAINING SYSTEM FOR EDUCATION AND DIAGNOSTIC PURPOSES

1. Introduction

The performance of combustion engines, in addition to structural parameters such as engine displacement and compression ratio, largely determines methods of controlling the combustion process. In order to use the fuel as effectively as possible, it is necessary to inject precisely the appropriate amount of fuel with respect to the volume of intake air inside the cylinders mixed with a little portion of exhaust gases delivered by the EGR system. Furthermore, the correct ignition timing of the compressed air-fuel mixture in the wide range of load, engine temperature and speed should be determined. The requirements mentioned above can be currently achieved only by mechatronics systems equipped with electronic controlled actuators. One of the ways to control the operation of actuators installed on combustion engines of road vehicles is the pulse width modulation method (PWM). The pulse width modulation is an efficient and versatile method based on the frequency and the duty factor of a square wave pulse signal providing effective control of the energy delivered to electrical loads. Application of the PWM method covers many areas extended to power electronics [1, 4, 6], measurement technology [2], automotive mechatronics [3, 5, 9] etc.. Furthermore, many novel variants of the basic PWM method with respect to its practical use were considered [1, 3, 10]. The PWM method enables the control of the average voltage across the load terminals resulting in average current and power. Moreover, the PWM technique is capable of contributing to an effective improve of speed control, forward and reverse operation and reduction of power losses.

2. The idea of automotive PWM laboratory training system

2.1 Power control methods used in automotive applications

Power control can be achieved by means of several methods shown in Fig. 1. Conventional methods provide a simple solution based on voltage drop across a rheostat (Fig. 1a) or a power transistor (Fig. 1b) connected in series with the controlled electric load. Unfortunately, the methods discussed above have many disadvantages. The voltage drop across the rheostat or transistor results in power loss $P_L$ and lower torque in the case of DC motors. The efficiency of the electric circuit becomes significantly lower. It is of particular importance if the controlled electric device is battery powered. Moreover, it is not possible to reverse the speed of DC motors without additional devices like relays or contactors. By contrast, the PWM is an effective technique based on the frequency and the duty factor of a square wave pulse signal. The duty factor $D\%$ is defined as a ratio of the $t_{on}$ time to the period $T$. The power applied to the electrical load can be controlled by

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the adjustable width of the applied input pulses resulting in the average DC voltage across the terminals of the load.

![Diagram](image)

**Fig. 1.** Rheostat (a), linear electronic (b) and PWM (c) control methods

The PWM method enables more effective speed control and reduces power loss. It can increase the lifetime of batteries because of longer time between charge cycles due to reduced power loss. The weight of thermal management components (radiators) may be reduced as well as the area of the transistor semiconductor layer. Hence, application of the PWM can be considered as a cost reduction strategy to lower material overhead.

### 2.2 The concept of designed PWM training system

Practical usage of the PWM method in automotive mechatronics covers mainly the power control of many actuators e.g. DC motors, solenoid valves, dimming of incandescent lamps and LEDs etc. A block diagram representing the idea of designed PWM training system is shown in Fig. 2.

![Diagram](image)

**Fig. 2.** Block diagram of designed PWM training system
The proposed PWM training system comprises a variety of resistive and inductive electrical loads utilized in automotive electrical systems. All of them are driven by a PC application providing individual tests and giving instructions to be performed by the ATmega328 microprocessor controller [11]. Generally, the PWM laboratory system can be used for the purposes of education or training. However, injectors capability and some properties of turbo charger control valves can be investigated by means of a pneumatic system comprising vacuum pump and two manometers. A photograph showing the front view of the discussed PWM training system is presented in Fig. 3.

![Automotive PWM training system – front view](image)

**Fig. 3. Automotive PWM training system – front view**

The proposed PWM laboratory unit is capable of providing many tests of automotive actuators with respect to variable duty factor and frequency of the PWM signal. An example of test results – a graph representing EGR valve functionality – output signal of the displacement sensor versus the duty factor is given in Fig. 4.

![EGR valve performance](image)

**Fig. 4. EGR valve performance**
The graph shown in Fig. 4 created from a table containing experiment results – displacement sensor signal as a function of increasing and decreasing duty factor – represents a hysteresis of the core of the tested EGR valve made of magnetic materials. The analysis of the curve shows that it is not possible to determine precisely the valve's position from the graph only. It is necessary to use a controller that takes into account feedback from the position sensor [11].

2.3 Application of the PWM training system in automotive diagnostics

The proposed PWM training system enables some tests of automotive electric actuators controlled by means of the PWM method e.g. fuel injectors, DC motors, solenoids etc. An application window of the diagnostic tool developed for fuel injectors testing purposes is presented as an example in Fig. 5.

![Fig. 5. Window of fuel injectors testing tool](image)

All parameters of injector’s control pulses shown in the diagram – namely: $t_1$, $t_2$, $T$, $k_1$, $k_2$ and the frequency are adjustable. Moreover, it is possible to refine the increase and the decrease of the majority of the parameters listed above. A vacuum pump shown in Fig. 2 and Fig. 3 is capable of air delivering for fuel injectors tests (instead of real gasoline). Injector current pulse duty factor values of open and closed injectors at nominal voltage 12V with respect to the frequency are listed in Table 1.

Table 1. Injector current pulse duty factor

<table>
<thead>
<tr>
<th>f Hz</th>
<th>duty factor %</th>
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<tr>
<td></td>
<td>open</td>
<td>closed</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>20.39</td>
<td>16.86</td>
<td></td>
</tr>
<tr>
<td>490</td>
<td>21.57</td>
<td>16.47</td>
<td></td>
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<tr>
<td>3921</td>
<td>27.06</td>
<td>15.29</td>
<td></td>
</tr>
<tr>
<td>31300</td>
<td>28.23</td>
<td>14.12</td>
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</tbody>
</table>
Air pressure measurement results are useful to recognize clogged injectors. The measured air pressure -40 kPa indicated closed fuel injectors. If the tested injector was clean and open, the pressure was reduced to -15 kPa. By contrast, the pressure -18 kPa was observed in the case of an open clogged injector.

3. Conclusions
The main aim of this work was the design of a useful training system for student’s laboratory activities. The proposed laboratory unit provides the following main benefits: getting students familiar with the pulse width modulation method and its application in automotive technology, testing of selected automotive actuators and their performance assessment. Finally, it may be concluded that some tests performed on the installed components: electric throttle, EGR valve, rotary idle speed regulator, interior light, injectors etc. can be useful as troubleshooting solutions for automotive actuators.

References:
Abstract

The pulse width modulation is an efficient and versatile method contributing to an effective improvement of energy control delivered to many automotive electrical loads - e.g. DC motors, solenoid valves, incandescent lamps, LEDs etc.. Basic features of a novel learning system for student’s laboratory activities were discussed. The application of the developed laboratory training system gives the following main benefits - getting students familiar with the pulse width modulation method and its application in automotive technology, performance assessment of selected automotive actuators. Moreover, some tests performed on the installed components can be useful as troubleshooting techniques for automotive electric equipment.

Keywords: PWM, pulse width modulation, automotive mechatronics, learning system, automotive diagnostics

METODA REGULACJI PWM W MECHATRONICE POJAZDÓW – STANOWISKO LABORATORYJNE DO CELÓW DYDAKTYCZNYCH I DIAGNOSTYKI

Streszczenie

Metoda sterowania oparta na modulacji szerokości impulsu (PWM) jest efektywnym i wszechstronnym sposobem regulacji energii elektrycznej dostarczanej do wielu rodzajów odbiorników stosowanych w pojazdach, jak na przykład silników prądu stałego, elektrozaworów, elementów techniki świetlnej wykorzystujących żarowe źródła światła i oparte na technologii LED. W treści pracy przedstawiono podstawowe cechy i właściwości nowego stanowiska laboratoryjnego zbudowanego na potrzeby prowadzenia zajęć dydaktycznych dla studentów. Praktyczne wykorzystanie przedstawionego stanowiska dało następujące główne korzyści - pozwoliło zapoznać studentów z ideą metody PWM i zakresem jej zastosowań w technice motoryzacyjnej oraz umożliwiło dokonanie oceny skuteczności działania wybranych samochodowych elementów wykonawczych. Stanowisko może ponadto stanowić narzędzie diagnostyczne umożliwiające sprawdzenie poprawności działania wybranych elektrycznych podzespołów pojazdów.

Słowa kluczowe: PWM, modulacja szerokości impulsu, mechatronika pojazdów, stanowisko laboratoryjne, diagnostyka pojazdów