# Electronic Controller of Automotive Valves

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***Abstract***

*One way to reduce fuel consumption is the use of control valves in the cylinder. The Time control of the valves can determine the character of the moving car and increases the output power of the engine. The conventional mechanical and hydraulic systems are not able to establish an adaptation time between motor and the instantaneous car situations. A perfect time adaptation between valves and instantaneous moving car is only possible with separate control of each valve. All controllers with sensor have either a technical problem or economically not affordable. Hence the senseless method has been motivated which is more flexible and free from the cumbersome calculations. The new intelligent valve works with electromagnetic force and is known as electromagnetic valve. It consist of two winding conductor with ferromagnetic cores that are located opposite to each other. This windings ferromagnetic core makes an Electrical - mechanical resonance system that provides the movement of the valves in the cylinder. In this paper, the "electronic controller" of the electromagnetic valve analysis and energy measurement circuit is designed, fabricated and tested.*

**Keywords** - *Electromagnetic valve, Electronic controller, Electromagnetic force, Electrical-mechanical resonance system, Time control of the valves*

## I. INTRODUCTION

Due to environmental protection measures, reduced generation of toxic materials and expensive fuel carriers such as petrol, gas, etc., reducing fuel consumption is one of the highest goals of automobile companies. To achieve these objectives, it is necessary to use smart engines such as using fuel smart feed, or smart regulation of cylinder combustion time [1]. Using electronic control of poppet valve is one of unknown potentials to reduce fuel consumption. In recent years, automobile companies have shown growing interest over such valves because they lead to reduced environmental toxic substances and fuel consumption by almost 15%. Conventional mechanical and hydraulic systems can only allow the valve movement to some extent. In other words, they can only cause a limited time control of valves. A multipurpose plan for completely electronic control of valve movement is to use electromagnetic poppet valves [2] [3]. This project has long been introduced but it was not practically developed because high landing speed of valves causes too much noise and reduced service life. Using sensors is not practically possible to regulate valve movement due to high vibration of engine and high temperature vibration. The research has shown that there are no suitable sensors to meet both technical and economic measures [4]. In automobile manufacturing industry, most valves controlled by sensors are implemented with high computational cost, deployment of high-power microcontrollers, or digital processors. Based on above mentioned issues, we were encouraged to apply a method without sensor with the removal of the above disadvantages. This article aims to introduce a sensor-free controller which takes essential information from" inductor-valve actuators" cycle in order to control poppet valves in cylinder. In this state, not only is sensor saved but also high computational cost can be reduced by selecting correct control algorithm. Opening and closing time of valves in cylinder can be regulated in a way that the output power is maximized. The most important advantages of variable controllable valves are as follow:

### A. Optimum energy consumption

With electronically-controllable valves, engine output power can rise up to even 50% and energy loss declines by up to 5% [5]. Studies in Porsche Company in Germany show that energy consumption is saved by almost 8-12% [4].

### B. Optimum behaviour of engine during turning on and off

With electronically controlled intake and exhaust valves of cylinder, hydrocarbon emissions decline by up to 60% when starting. Cylinders can be separately turned off (in multi-cylinder engines). Therefore, turned off cylinder can change, leading to the uniform distribution of heat in the engine [4].

### C. Controllable output of compressed gas from cylinder

Dense fuel exit is objectively performed by electronic control of cylinder output valves so that the effect of engine dynamometer rises. As a result, extra force is not required in automobiles for braking [3]. If both intake and exhaust valves, and accordingly all cylinders, are controllable, valve timing can be completely benefited to optimally control the automobile. Therefore, an economic method was introduced which works with electromagnetic force. The basis of this method is associated with the vibration of a metal plate which moves between two electromagnetic selves. (Fig.1). Metal plate movement is directly transferred to valves by a rod. Using such electromagnetic valves leads to considerably reduced costs due to the absence of hydraulic system.

## II. ELECTROMAGNETIC VALVES

### *A. The basis of electromagnetic valves*

Electromagnetic valve is based on the law of electromagnetic induction which makes an electro-mechanical resonance system by Electro-magnetic actuator (with two auxiliary springs). Two selves against each other, which have been wired on an electromagnetic core, form this electromagnetic actuator (Fig. 1). A metal plate is located on the central axis of these two selves (y direction) which can freely move between them. When electric current passes through selves, passing electromagnetic flux and accordingly electromagnetic force is generated, leading to pulled metal plate and accordingly valve rod. Two springs are taken into account in upper and lower section of selves in order to support the metal plate movement due to high electric current for moving the metal plate from a situation to another. Springs are located in a way the metal plate is in the middle of two selves in static condition. When the metal plate is in either upper or lower situation, 2-3 A electric current is required in order to keep it [3]. When electric current is cut, the metal plate is accelerated toward the other side by spring force. The metal plate cannot move completely to other side by only spring force due to energy loss. Energy loss, which is necessary to move the metal plate completely to the other side, is given in an electric energy form to inductor. The electric energy injection is performed by an electronic controller. A constant current is injected to the inductor during metal plate vibration. High current, however, is required to overcome energy loss and keeping the metal plate in peak upper or lower condition. Therefore, two different currents are used for metal plate movement. ($I_F$ Almost high current to trap the metal plate and $I_H$ almost small current to keep the metal plate). These values are almost 6-8 A for $I_F$ and 2-4 A for $I_H$. A complete analysis is not possible for electromagnetic valve behavior. Approximate analysis is, however, possible because the ferromagnetism material shows an extreme non-linear behavior such as hysteresis behavior or saturation behavior [8].

### *B. Electromagnetic valve control*

The main task of valve controller unit is to supply clear electric current (at certain times) in electromagnetic valve actuator unit. To this end, key controllers are appropriate tools [5] [7]. Fig. 2 shows a sample of these controllers. $L_A$ and $R_A$ show inductor and internal resistance of actuator unit. Inductor current passes $R_{sense}$ by $T_2$ lower transistor conductivity (by E signal).

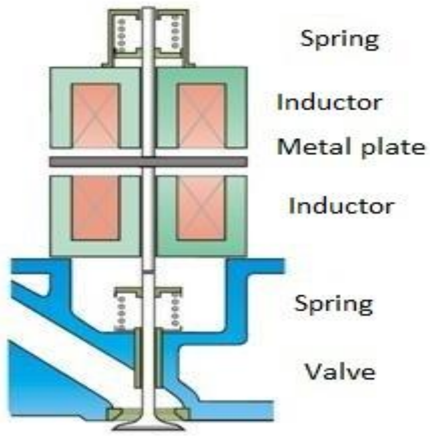


**Fig.1: Electromagnetic valve**

$R_{sense}$ is to evaluate passing current from the inductor. The resistance is 20 mΩ to prevent the loss. The voltage at two heads of $R_{sense}$ resistor is compared with upper and lower limit which determines the inductor current by $C_1$ and $C_2$ comparators. If the passing current from $R_{sense}$ is larger than upper limit value, $T_1$ transistor does not conduct ($C_1$ comparator is minimized). If the passing current from $R_{sense}$ is smaller than the lower limit value, then $T_2$ transistor conducts again ($C_2$ comparator is minimized). The voltage at two heads of the inductor is regulated in such a way that the passing current in within the range by alternative switching on and off of $T_1$ transistor, while $T_2$ transistor still conducts [3]. The circuit in Fig. 2 can be studied in three states:

#### *1) If both $T_1$ and $T_2$ transistors conduct*

In this state, electric current passes $U_{DC}$ supply, $T_1$ transistor, $R_A$ resistor, $T_2$ transistor, and $R_{sense}$ resistor. The slope of electrical current rise equals:

$$\frac{U_{DC}}{L_A} \approx \frac{U_{LA}}{L_A} = \frac{dI_{LA}}{dt}$$

Voltage drop is negligible in resistors ($R_A \approx 0.5\ \Omega$, $R_{sense} \approx 20\ m\Omega$)

#### *2) $T_2$ TRANSISTOR CONDUCTS WHILE $T_1$ TRANSISTOR DOES NOT*

Passing current from $L_A$ returns to $L_A$ again through $R_A$ resistor, $T_2$ transistor, $R_{sense}$ resistor, $D_2$ diode. Since energy loss is ignorable in this state, electric current gradually declines.

#### *3) NONE OF $T_1$ AND $T_2$ TRANSISTORS CONDUCT*

Passing current from $L_A$ returns to $U_{DC}$ supply by $D_1$ and $D_2$ diodes (The stored energy in $L_A$ inductor returns to $U_{DC}$ supply and electric current rapidly declines to zero. Fig. 3 shows a simulation of passing current and voltage at two heads of $L_A$

inductor with controlling signals of $T_1$ and $T_2$ transistors. In order to regulate electric current, both transistors first conduct and electric current slope rises in linear form (Eq. 1). When the electric current does not exceed the upper limit, A state changes to B. In ideal state, current keeps its moment value which declines exponentially with large time constant in B state due to electric energy loss. After mode change in B, electric current reaches its lower limit after a while. In this state, $T_1$ transistor conducts again. $T_2$ transistor always conducts and it turns off only when the passing current from $L_A$ and $D_1$ and $D_2$ diodes declines rapidly. The voltage at two heads of $L_A$ inductor is too small in B state ($U_{LA} \approx$ -1 V) because the voltage at two heads of inductor is almost twice as much as the voltage at two heads of $D_2$ diode. The voltage at two heads of $R_{sense}$ resistor is ignorable and the voltage is too small at two heads to $T_2$ transistor ($U_{DS,2}$). The slope of electric current decline ($\frac{U_{LA}}{L_A} \approx -\frac{U_{D2}}{L_A}$) is small compared to the slope of electric current rise ($\frac{U_{DC}}{L_A} \approx \frac{U_{LA}}{L_A}$). Since $T_1$ transistor turns on and off at certain intervals, the current and consequently the electric voltage of $L_A$ inductor remains constant between the upper and lower threshold. In other words, the circuit changes between A and B states until the electric $L_A$ inductor voltage and current remain constant at the permissible range. The electric current rises in inductor at t= 2ms (Fig. 3). The energy is supplied from t= 2 ms. From this time onward, the metal plate starts to move. For A state, electric current slope is positive. Electric energy loss is positive in this state. In B state, electric current slope is negative. Therefore, a negative value appears for the multiplication of $L_A$ voltage and current in inductor. In other words, the circuit does not receive no energy from the network. Therefore, a circuit needs to be designed where the energy is set on zero in B state in order to calculate the given energy [7].

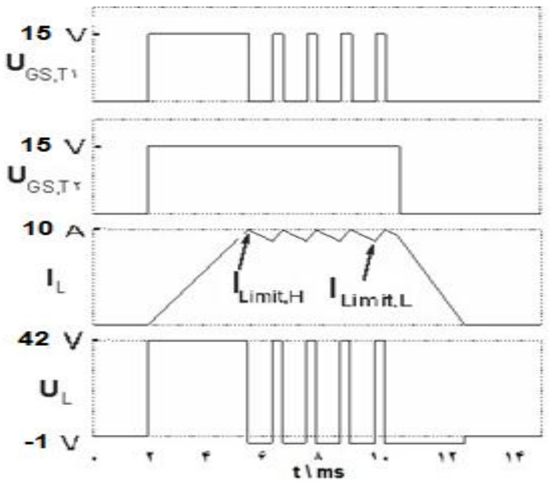


**Fig. 3: Simulation diagram of voltage and current in inductor and conducting signals in T1 and T2 transistors**

## III. CONTROLLER UNIT CIRCUITS

There are several methods to fulfill controlling stages of electromagnetic valve (Fig. 1) such as signal digitalization and their complete analysis through signal digitalization or analysis via analogue circuits. The procedures would be difficult if done separately. For example, $\frac{dI_{LA}}{dt}$ derivative is only possible by many sampling for signal digitalization or various sections need to be adapted in analogue method. Therefore, a combination of analogue and digital methods were selected for the analysis of signals [3]. First, voltage and current signals are prepared in analogue form (The strengthening of the signals, making derivatives, and integrals of them). Then the output signals are digitally analyzed. Output signals of analogue circuit are given to the micro control (μC). Micro control generates power transistor supply signals ($T_1$ and $T_2$) by the help of a high voltage driver according to the algorithm in order to create the current in $L_A$ inductor by turning on and off these transistors (Fig. 3). While forming analogue signals, measured electric voltage and current signals need to go under derivation and integration in order to determine the position of electromagnetic valve metal plate. This can be performed by Fig. 4. Integrating the voltage of $L_A$ inductor is performed by the calculation of potential difference between the two ends of the inductor at the negative end of $OP_2$ reverse operational amplifier input (as integrator) (with the algebraic sum of currents). T3 transistor is employed to regulate the integration again. Electric voltage is used to integrate and derivate current. Passing current from $L_A$ inductor appears at $R_{sense}$ voltage. The voltage at two ends of $R_{sense}$ resistor is obtained by a differential amplifier and a current converter. This way, we can achieve a larger band width and CMRR for higher frequencies. To integrate the electric current, $OP_4$ reverse operational amplifier is employed. $C_2$ capacitor empties by $T_4$ transistor conduct (for integrator reset) and OP5 reverse operational amplifier and $C_3$ capacitor play role for electric current derivate.

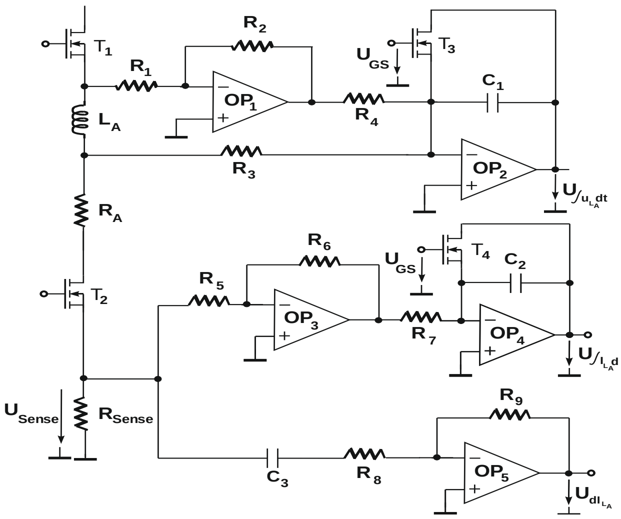


**Fig. 4: Derivative and integrator circuits [5]**

## IV. ENERGY MEASUREMENT CIRCUIT

Fig. 5 shows energy measurement circuit. This circuit separately calculates the given energy to each inductor in electromagnetic valve actuators unit (upper and lower inductor in Fig.1). In order to determine the consumed energy, power consumption needs to be calculated first. This is achieved by the multiplication of consumed voltage by current in inductor. To calculate the power consumption of an inductor, three voltages of $D_2$ diode ($U_{Diode,\,2}$) inductor ($U_{LA}$), and resistor ($U_{sense}$) need to be taken into account. ( $U_{diode,\,2}$ is the $D_2$ diode voltage at B state). $P_{in}$ ($P_m$) and $E_0$ are consumed power and energy, respectively. The energy consumption of each valve is achieved by total sum of energy consumption of upper and lower inductors of actuator unit. Inductor voltage ($U_{LA}$) is connected to the negative end of $C_3$ comparator and $N_1$ voltage divider (with $R_{11}$ and $R_{12}$ resistors). Resistor voltage ($U_{sense}$) supplies $N_2$ voltage divider (with $R_{13}$ and $R_{14}$ resistors). $N_1$ and $N_2$ dividers were employed due to the adapting to the inputs of multipliers (maximum multiplier voltage is 1.5 V). $C_3$ comparator is connected to $T_5$ transistor. This transistor plays an important role in this circuit. T5 transistor drain is connected to the first $N_1$ voltage divider which both forms the first branch of multiplier input. The second $N_2$ voltage divider output forms the second branch of multiplier input. $R_{10}$ resistor and $D_{Z1}$ Zener diode are connected to the negative end of $C_3$ comparator. $R_{10}$ resistor was employed to supply the essential electric current for Zener diode. Zener diode voltage plays the role of $D_2$ diode voltage in B state. For positive values of $U_{LA}$, A voltage is Zener diode voltage. In other words, Zener diode conducts and $C_3$ comparator output voltage becomes negative. For negative $U_L$ values, A voltage is negative and consequently $C_3$ comparator output voltage becomes positive. When C3 comparator output voltage is negative, $T_5$ transistor does not conduct ($T_5$ transistor gate voltage is negative). Therefore, $U_L$ is the voltage of the first multiplier input branch. It means that multiplier multiplies $U_L$ and $U_S$ for $U_{LA}$ positive values ($U_{LA} \approx 42$ V). When C3 comparator output voltage is positive, $T_5$ transistor conducts ($T_5$ transistor gate voltage is positive). Therefore, $U_{DS,2}$ voltage of $T_5$ transistor is too small (close to zero). It means that the output voltage of multiplier is almost zero. So, we are able to set the computational power for negative $U_{LA}$ values. Multiplier output voltage is amplified by an $OP_6$ reverse amplifier with $R_{16}$ and $R_{17}$ resistors. $N_3$ voltage divider with $R_{15}$ resistor and $R_P$ potentiometer is used in positive branch for neutralizing $OP_6$ amplifier offset voltage (A differentiator is made to neutralize off-set voltage by $N_3$ voltage divider which has a potentiometer). To calculate energy consumption, $P_{in}$ output power ($U_{in}$ output voltage) integrated by $OP_7$ integrator (by $R_{18}$ resistor and $C_4$ capacitor). $T_6$ transistor is employed to regulate the $OP_7$ integrator again. To show the numbers on a computer monitor, analogue outputs are sent to a µC.

## V. CONCLUSION

In this article, an electronic controller of cylinder valve is analyzed (or any other mechanical motor). This controller generates a mechanical-electric resonance system with an electromagnetic actuator. (According to the electromagnetic induction law). Two inductors against each other, wired on an electromagnetic core, form this electromagnetic actuator. When passing electric current from one of inductors, passing electromagnetic flux and consequently magnetic force leads to pulling metal plate and valve rod toward it. Alternate supply of electric current to inductors causes the connected valve moves between two inductors. While controlling the movement, the speed and any other variable in automobile are controlled by electric voltage and current. Electronic controller was tested by installing on a motor with DC supply and the expectations were met.

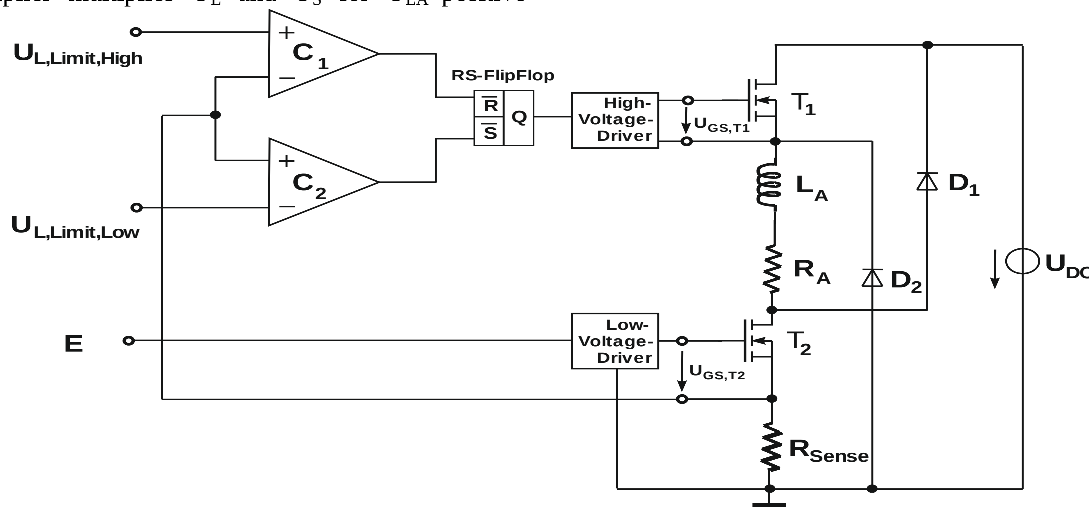


**Fig. 2: Controller circuit of electromagnetic valve**

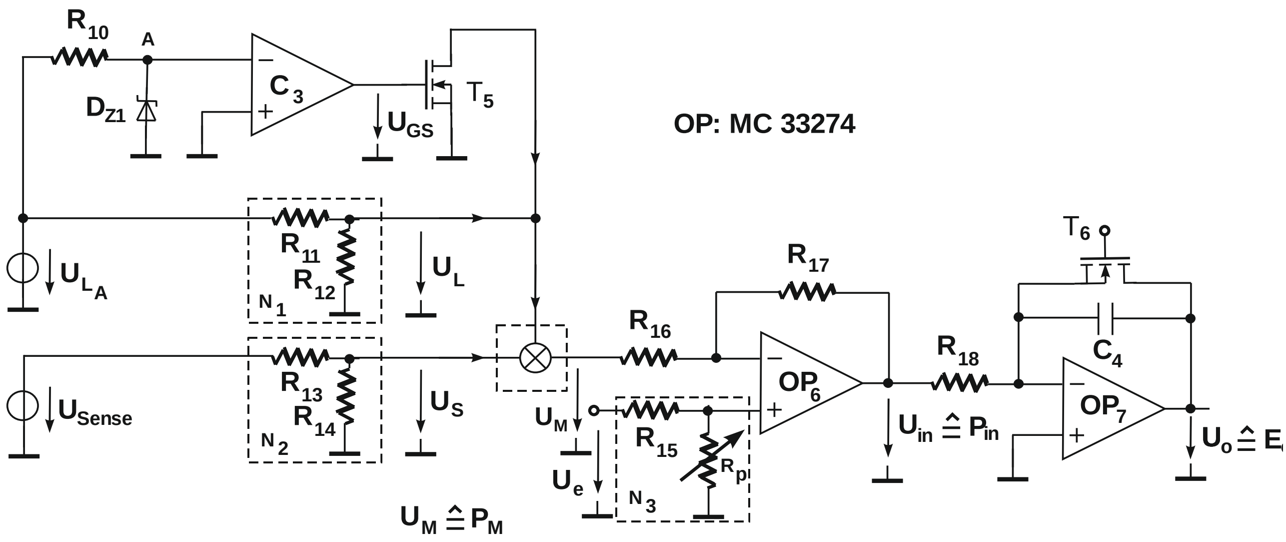


**Fig. 5: circuit of Energy measurement**

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